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SOME ASPECTS OF RECENT HIGH PRESSURE INVESTIGATION.*

BY

JOHN JOHNSTON, D.Sc.,

Geophysical Laboratory, Carnegie Institution of Washington.

TWENTY-FIVE or thirty years ago the belief was common among chemists that the field of inorganic chemistry was largely worked out, that little of importance remained to be done. This was indeed largely true so long as the methods of chemical investigation were limited to those generally used at that time; but the application of later and more useful methods, and the extension of investigation to a wide range of conditions, have shown that this view is very far from the true one. Indeed, it is now manifest that what is known is but a mere fraction of that which remains to be ascertained; and for the following reason. Until within a very few years, students of chemistry—and for that matter, of physics, too—had occupied themselves almost exclusively with the properties and behavior of matter within a very restricted range of conditions. But, manifestly, if we are to know completely the properties of substances and their relations one to another, we must extend our investigations to cover the whole range of tem-

* Presented at a meeting of the Section of Physics and Chemistry, held Thursday, October 26, 1916. No attempt has been made to make the list of references complete; many of the papers cited, which are those with which the writer happens to be familiar, give references to earlier work.

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perature and pressure within which each substance is capable of existence. Hitherto the extent of the temperature range studied has been little beyond the boiling point of water, in general; and the sole pressure has been, practically, that of the atmosphere. It follows, therefore, that we have been dealing in the main with a very thin strip of the surface which we may consider to represent the behavior of the substance throughout the range of temperature and pressure within which it is capable of existence. Putting it in another way, one may say that our chemistry has been that of the 25° horizon; but it is obvious that the chemistry of the 250° horizon would differ considerably, and that at the 1000° horizon the mutual relationships would be still simpler—the myriad of organic compounds would then be reduced to two or three, and the complications in inorganic chemistry would be very markedly reduced.

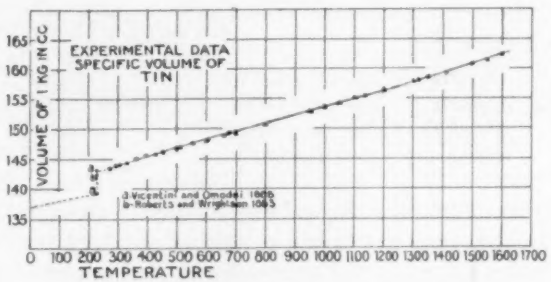
Now since we have investigated such a relatively small part of the whole subject-matter, it is hardly surprising that we should have been unable to detect many thorough-going regularities in the properties of matter; because to discover such regularities it is obviously necessary to make our observations at some kind of corresponding temperatures and pressures—at equal fractions of the critical constants, or whatever may prove to be the corresponding conditions. In any case it is unsafe to assume that ordinary temperature and pressure are anything but arbitrary conditions for comparison. Consequently, to take an example, it is unreasonable to expect that what is known as the law of Dulong and Petit—namely, that the product of specific heat as ordinarily obtained and atomic weight of the elements in constant—should hold for all the elements; indeed, it is surprising that this law holds so well as it does. And, indeed, there is now no question that extended investigation in this sense will increase greatly the scope and utility of chemical generalizations.

In discussing the effects producible by pressure, one must always distinguish carefully between uniform (or pure hydrostatic) pressure and non-uniform compression (which is equivalent to a stress); for the former is incompetent to achieve some of the results which may be brought about by the latter. In what follows we shall always consider the pressure to be uniform, unless the contrary is expressly stated.

I wish now to emphasize the point that changes of pressure and of temperature produce analogous effects—that pressure and temperature are, in chemical parlance, analogous variables. In order to do this, let us consider for a moment what happens when a single crystalline substance is heated slowly.

When heat is slowly supplied to crystals of a single substance the properties (*e.g.*, volume) of the latter change slowly and continuously; but when it has reached a certain temperature, there is an abrupt change of properties and the crystals melt, the temperature at that time being the melting temperature of the solid. Incidentally it may be observed that one cannot determine accurately the melting temperature of a crystalline substance by ob-

FIG. 1.



The change of volume of tin with temperature.

serving its appearance merely; but must do it by observing the abrupt change in whichever of its properties is most conveniently investigated—*e.g.*, its volume, heat content, electrical conductance. After melting is complete, further addition of heat is accompanied anew by a gradual change of properties, the rate of change of each with temperature being that characteristic of the substance in liquid form. This is illustrated by Fig. 1, which shows the change of specific volume of metallic tin with temperature;[1] the abrupt change in volume at the melting temperature (231.9°) is about 5.5 per cent. of the volume of the solid at that point. Conversely a pure liquid, when cooled slowly (or in such a way as to obviate undercooling), will freeze at a definite temperature to a crystalline solid, with a corresponding abrupt change

[1] Taken from the paper of Day, Sosman and Hostetter, *Am. J. Sci.*, **37**, 1 (1914).

in properties at that temperature. Now in precisely the same way, such a liquid, kept at constant temperature,[2] and subjected to gradually increasing pressure, will crystallize at a definite pressure—this being the freezing pressure corresponding to the particular temperature. For example, the freezing temperature of water is 0° at 1 atm., −1° at 100 atm.; or one may say equally well, the melting pressure of ice is 1 atm. at 0°, 100 atm. at −1°. Likewise the freezing temperature of mercury is −38.8° at 1 atm., its freezing pressure at 0° is 7600 atm.

Now it may happen that a crystalline substance when slowly heated shows at a definite temperature an abrupt change of properties, but transforms not to a liquid but to a second crystalline form; and on further heating this second form may change to a third or even a fourth, which finally melts to a liquid. An example of this is the substance silica, which shows the following series of changes:[3]

α-quartz	→	β-quartz		575°
β-quartz	→	tridymite	about	870°
tridymite	→	cristobalite	"	1470°
cristobalite	→	liquid	"	1600°

Fig. 2[4] exhibits how the volume of quartz changes when it is heated. In this case the break is neither so large nor so abrupt as it is with metals; but the curve shows without question that a transformation has taken place at 575°, for the volume *diminishes* with rising temperature for an interval beyond 575°. The other three changes run so very slowly that they are not visible on this diagram; the appropriate transition temperatures were fixed by other methods.

This phenomenon—namely, the ability of a chemical substance to appear in more than one crystalline form—is known as polymorphism; and there are many well-known examples of it. Thus, sulphur appears in at least four forms, phosphorus in four, metallic tin in two, calcium carbonate and magnesium metasilicate in three each, and so on. Now polymorphism was quite generally

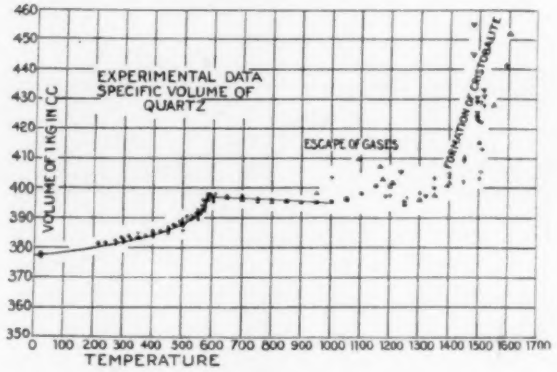
[2] It may be remarked that ordinarily when we speak of melting or freezing point, the assumption of constant pressure is implicit.

[3] See C. N. Fenner, "The Stability Relations of the Silica Minerals," *Am. J. Sci.*, **36**, 331 (1913).

[4] Taken from the paper of Day, Sosman and Hostetter, *Am. J. Sci.*, **37**, 1 (1914).

supposed to be a more or less exceptional phenomenon; but we are learning that it occurs very commonly, that so soon as we investigate a substance through a wide range of conditions, we are quite likely to discover that it can exist in more than one form. And just as other forms appear at higher temperatures, so do they appear at higher pressures; the latter case is less familiar to us merely because it has been investigated less seldom. As an illustration, take the substance H_2O, which exists in at least 5 distinct solid forms—ordinary ice, and 4 other varieties, each of which is *denser* than liquid water; to this we revert later.

FIG. 2.



The change of volume of quartz with temperature.

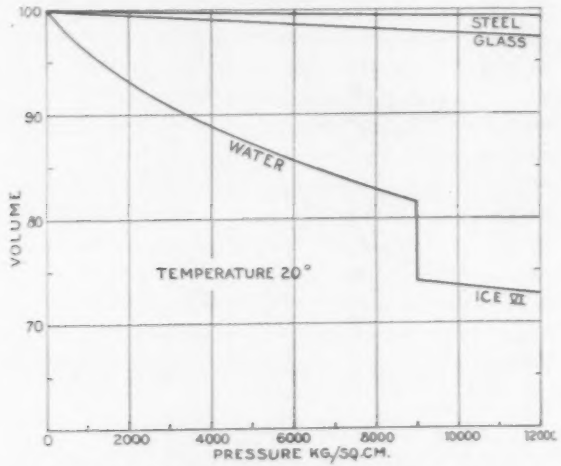
These examples serve to show the great analogy between the effects of the variables temperature and pressure. Moreover, the fact that the study of a substance through a wide range of conditions frequently results in the discovery of polymorphic forms indicates the great importance of such work to the problem of ascertaining the precise relations between the several forms, crystalline and liquid;[5] and, be it remarked, it is only by varying pressure that we can in such cases study the process through a range of temperatures.

The effects of high hydrostatic pressure upon most properties and phenomena have been very generally overrated, largely be-

[5] See, in particular, recent papers by Bridgman, *Proc. Am. Acad.*, **52**, 57, 91 (1916).

cause of a confusion of ideas and because it was convenient to have some factor to which one could attribute phenomena not manifestly explicable on the basis of known factors. Indeed, one may say that most of the statements about high pressures usually encountered can be accepted only with considerable reservations, and many of them are altogether misleading—for instance, the assertions that pressure causes certain reactions between solids to proceed. But in some directions the effects producible by high pressures have frequently been underrated. In most text-books one will find the statement that fluids are incompressible; but this

FIG. 3.



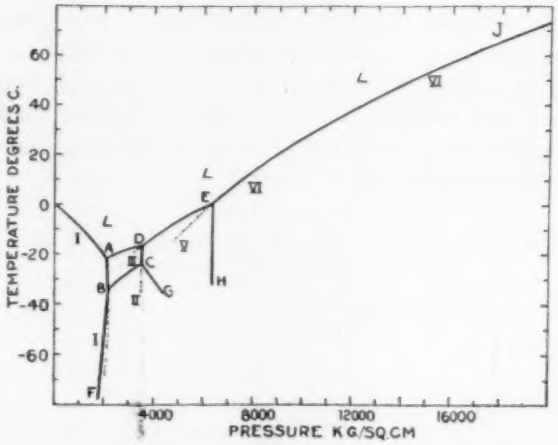
The change of volume of steel, glass and water with pressure.

is one of those assertions that hold only so long as one does not study the phenomenon too closely. As a matter of fact, the volume of a fluid can be reduced 25 per cent., and that of a solid even can be made appreciably smaller. Fig. 3 shows the change of volume of steel, glass and water by hydrostatic pressure; you see that a pressure of 10,000 atm. (150,000 lbs., or 75 tons, per square inch [6]) causes 100 volumes of steel to shrink to 99.4 vols., and 100 volumes of glass to 97.8 vols. The result for steel is typical of the metals, that for glass is typical of silicates and min-

[6] It may be remarked that the pressure in a steam boiler is rarely more than 225 lbs. per square inch, or 15 atm.

erals generally.[7] In the case of water at 20° we see that even 1000 atm. has caused 100 volumes of water to occupy only 96 vols., and that this change of volume goes on progressively—though at a diminishing rate—as the pressure is increased; but at 20°, when a pressure of 9000 atm. is applied, there is a sudden diminution of volume of 7.5 per cent. (of the original volume), followed by a smaller compressibility than before when pressure is further increased. Now what does this discontinuity mean? It means the freezing of the water with the formation of a kind of ice denser than liquid water; that at 20° the freezing pressure

FIG. 4.



Equilibrium diagram for water—liquid and five solid forms.

of water is 9000 atm., above which pressure we are measuring the compressibility of this form of ice. This curve is typical of all liquids hitherto investigated, for their volume at 10,000 atm. is about 75 to 80 per cent. of their volume at 1 atm.;[8] the pressure at which they freeze differs, of course, from one liquid to another, just as the freezing temperatures at ordinary pressure differ.

[7] There are, of course, differences of compressibility from one metal to another, which would hardly be evident on the scale of Fig. 3; for the compressibility is also a periodic function of the atomic weight of an element. (See T. W. Richards, *J. Am. Chem. Soc.*, **37**, 1653 (1915).

[8] See Bridgman, *Proc. Amer. Acad.*, **49**, 1 (1913).

The similarity between this graph for water and that (in Fig. 1) showing the change of volume of liquid tin with diminution of temperature, illustrates again the point that the variables temperature and pressure are completely analogous. The main difference (which, indeed, depends upon our system of units) is that a change of pressure of 1000 atm. will in general effect no more in condensed systems (*i.e.*, systems without a vapor phase) than a change of temperature of 10°; this is evident from the diagrams, and we shall encounter further examples of it.

The freezing pressure of water at 20° is 9000 atm.; now if similar experiments are made at other temperatures, the appropriate freezing pressures are determined. In this way, or by analogous experiment, we obtain the melting (or freezing) curve of the substance, *i.e.*, the curve which shows the relation between melting temperature and pressure or, if you please, between melting pressure and temperature. In Fig. 4 is given the freezing curve of liquid water, as determined by Bridgman;[9] some of the numerical data are collated in Table I.

TABLE I.

Numerical Data Pertaining to the Equilibrium Diagram for Water—Liquid and Five Solid Forms (After Bridgman)*

Pressure kg. per sq. cm.	Corresponding Temperature	Phases in Equilibrium
1	0.0	Freezing-point: ice I-liquid
1,000	− 8.8	" " " "
2,000	−20.15	" " " "
2,115	−22.0	Triple point (*A*): ice I-ice III—liquid
2,170	−34.7	" " (*B*): " " —ice II
3,510	−24.3	" " (*C*): ice III-ice V—ice II
3,530	−17.0	" " (*D*): " " —liquid
4,500	−10.2	Freezing-point: ice V-liquid
5,500	− 4.2	" " " "
6,380	+ 0.16	Triple point (*E*): ice V-ice VI-liquid
8,000	+12.8	Freezing-point: ice VI-liquid
12,000	+37.9	" " " "
16,000	+57.2	" " " "
20,000	+73.6	" " " "

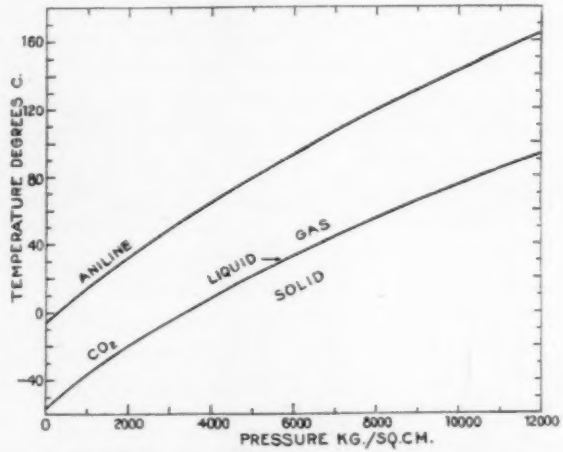
* The notation ice IV was not used, as it had already been assigned by Tammann to another reputed form, which differs very little from ordinary ice (I): the existence of this form, which was not encountered by Bridgman, is very doubtful.

As is evident from the diagram, the complete freezing curve is made up of four distinct curves, which represent the equilibrium between liquid (L) and four different kinds of solid water

[9] P. W. Bridgman, *Proc. Am. Acad.*, **47**, 439 (1912).

(I, III, V and VI). As the pressure is increased from 1 atm., the freezing temperature is lowered, approximately 1° for each 100 atm., in accordance with the fact that the specific volume of ordinary ice (ice I) is greater than that of liquid water; but when the pressure has become 2115 atm., the freezing temperature begins to rise again and we are now dealing with the equilibrium between liquid and another form of ice, a form which is denser than the liquid. Incidentally this shows that the maximum pressure obtainable by cooling water in a closed vessel is 2100 atm.,

FIG. 5.



The melting curves of aniline and solid carbon dioxide.

that pipes capable of withstanding this pressure would never burst by freezing of the water. As the pressure is raised beyond this point, the freezing temperature proceeds along the curves AD, DE, EJ successively, each of these three solid forms being denser than the liquid. Again, if we keep the temperature constant at −20° and increase the pressure gradually, the following sequence of events will occur: at 200 atm. ice I will melt, but at 2500 atm. the liquid will freeze again to III; this in turn will at 3500 atm. pass over into V, which at 6300 atm. will transform to VI. At any temperature higher than 0° (the ordinary freezing point of water), no solid will appear until the pressure exceeds 6400 atm., when VI will appear at a pressure depending upon the

temperature, *e.g.*, hot water at 73° will freeze to a solid under a pressure of 20,000 atm.

The general type of melting curve is that of ice VI; it is more readily apparent from Fig. 5, on which the curves for aniline and CO_2 have been drawn. The curves are convex to the pressure axis; or, in other words, each successive increment of pressure produces a smaller effect—and indeed, this statement is true generally no matter what be the property in question. This is illustrated also by Table II, in which the numerical data[10] for sev-

TABLE II.

Melting-Curves of Various Substances (After Bridgman)

Pressure Kg. Per Sq. Cm.*	Mercury		Potassium		Sodium		Nitrobenzol		Carbon Dioxide	
P	*t*	Δ*t*	*t*	Δ*t*	*t*	Δ*t*	*t*	Δ*t*	*t*	Δt
1	−38.85		62.5		97.6		5.6		−56.6	
		5.10		16.2		8.6		21.9		19.3
1,000	−33.75		78.7		106.2		27.5		−37.3	
		5.09		13.7		8.1		21.2		16.8
2,000	−28.66		92.4		114.3		48.7		−20.5	
		5.09		12.3		7.6		19.9		15.2
3,000	−23.57		104.7		121.9		68.6		− 5.3	
		5.09		11.1		7.2		18.8		13.8
4,000	−18.48		115.8		129.1		87.4		+ 8.5	
		5.08		10.2		6.9		17.7		12.7
5,000	−13.40		126.0		136.0		105.1		21.2	
		5.08		9.4		6.6		16.9		11.7
6,000	− 8.32		135.4		142.6		122.0		32.9	
		5.07		8.7		6.3		16.1		11.1
7,000	− 3.25		144.1		148.9		138.1		44.0	
		5.06		8.1		6.1		15.5		10.6
8,000	+ 1.81		152.2		155.0		153.6		54.6	
		5.06		7.5		5.9		15.1		10.2
9,000	6.87		159.7		160.9		168.7		64.8	
		5.05		7.0		5.7		14.8		9.9
10,000	11.92		166.7		166.6		183.5		74.7	
		5.04		6.6		5.4		14.5		9.6
11,000	16.96		173.3		172.0		198.0		84.3	
		5.03		6.2		5.2		.....		9.3
12,000	21.99		179.5		177.2		.....		93.6	

* 1 atm. = 1.033 kg. per sq. cm.

eral substances have been brought together. The actual slope (dT/dP) of the curves differs from one substance to another, but only within comparatively narrow limits—from a few degrees

[10] Taken from Bridgman, *Phys. Rev.*, **3**, 153 (1914).

up to 40° per 1000 atm.; it is determined at any point by the relation

$$\frac{dT}{dP} = \frac{T\Delta V}{\Delta H} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

i.e., by the ratio,[11] at that point, of the change of volume (ΔV) on melting to the heat change on melting (ΔH, the so-called latent heat). ΔH is always positive, ΔV is positive for all except two substances—ice I and metallic bismuth—so far as known; accordingly these are the only solids whose melting temperature falls as the pressure is increased.[12]

It is of interest to inquire what is likely to be the course of the melting curve at still higher pressures. Tammann has argued, on an altogether insufficient experimental basis, for the existence of a maximum on the curve, which implies that by the application of *sufficient* pressure all solids could be melted, no matter what the temperature. Now from equation I it follows that there would be a maximum on the curve only if ΔV becomes zero at some pressure; but Bridgman's work shows that ΔV diminishes more and more slowly with increase of pressure but shows no sign of vanishing. Accordingly we believe that the melting temperature continues to rise indefinitely with increasing pressure, although the melting curve becomes gradually flatter and flatter. Again, some writers have expressed the belief that the melting curve has a critical end-point analogous to the critical end-point of the liquid.[13] From thermodynamic principles it follows that the

[11] It may be remarked that there is no general relation between ΔH and ΔV, for we may have a large latent heat associated with a small volume change, and vice versa.

[12] In the system water, as we have seen, this holds only up to a pressure of 2100 atm., at which point ice I ceases to exist.

[13] This last point is of some general importance, so let us digress for a moment to consider the significance of a critical end-point. If a liquid is heated up in a confined space so that it is in contact with its saturated vapor (*e.g.*, water and saturated steam), the vapor pressure gradually rises; and the properties of the two phases resemble each other more and more closely until at a definite temperature they cease to be distinguishable. For water this happens at about 370° and 200 atm., the density of each phase being about 0.3. The point at which they cease to be distinguishable is the critical end-point of the liquid. At temperatures lower than this, continuous concentration of the vapor will always result ultimately in its condensation to liquid; at higher temperatures no liquid will form no matter what the concentration (pressure) of vapor. In other words, at a definite temperature, the liquid

condition for a critical end-point is that ΔV and ΔH should vanish simultaneously, but Bridgman's work shows absolutely no indication of such a thing—indeed, ΔH, instead of tending towards zero, shows rather a tendency to increase at higher pressures. Moreover, it is hard to conceive of a *continuous* transition (as the existence of a critical end-point would require) from the orderly arrangement characteristic of a crystal to the unordered distribution characteristic of a gas.

There is thus, as we have seen, no reason for believing that the melting curve either passes through a maximum or comes to a critical end-point; and it has been found that there is no break on this curve when the temperature reaches the critical temperature of the liquid phase. This is illustrated by the curve for CO_2 in Fig. 5; namely, at a pressure of about 5800 atm. the melting temperature of solid CO_2 has reached 31°, the critical temperature of liquid CO_2; at pressures higher than this the solid sublimes or passes directly into a gas, and the curve then represents the equilibrium between gaseous CO_2 and solid CO_2, though there is, of course, no break at the critical end-point of the liquid. Consequently it is in this case practicable to pass from *gas* (not vapor, for it is above the critical temperature) to crystalline solid merely by change of pressure. This suggests that any gas can be converted into a solid by the application of sufficient pressure, that one could in this way get solid air even at ordinary temperature provided only that the pressure required be not in excess of the maximum which a containing vessel can be made to withstand. And this fact constitutes another reason for believing that the interior of this earth is substantially solid; so that the laboratory evidence, when properly interpreted, yields the same conclusion as that reached on totally different grounds by those who have considered the speed of transmission of earthquake waves, the existence of tides within the earth, and such problems.

Let us now revert for a moment to the subject of polymorphism. The study of the substance water over a wide range of pressures has resulted in the discovery that there are at least five different forms of solid water, the relations between these five being given in Fig. 4. This is perfectly analogous to the case of SiO_2, where the other forms appear at higher temperatures.

phase ceases to exist. Moreover, by appropriate manipulation of the conditions one can always achieve a *continuous* transformation from gas to liquid.

Thus new crystalline forms may appear at high pressures just as they appear at high temperatures; and in either case, such forms may often persist at ordinary pressure, just as tridymite and cristobalite persist when once they have formed. We may expect, therefore, that extended pressure investigations will yield substances hitherto unobtained or unknown, and that some of these will prove to be of technical importance. In connection with the possibilities in this direction I would point out the new modification of phosphorus recently described by Bridgman.[14] He had heated ordinary yellow phosphorus to about 200° and 12,000 atm., and kept it under those conditions for several minutes when a sudden large drop in pressure occurred; on opening the bomb he found a new variety, much denser (2.7) than either the red (2.3) or yellow (1.9) form; it is grayish-black like graphite, is ignited with difficulty by a match, and cannot be exploded by a blow from a hammer. This substance may not have any technical importance, but its formation—which apparently does not occur except under those extreme conditions—illustrates the possibilities.

We have been considering the effect of pressure upon the state of equilibrium of the several forms of a substance. Now the position of equilibrium determines whether a given change may, or may not, take place under given conditions; but, even though the change is possible, it will not take place unless its rate under the particular conditions is appreciable. In other words, the non-occurrence of a change may be due to a laziness, as opposed to an inability, to proceed under the given conditions. The rate of reaction is therefore an important factor; but whereas it is increased enormously by rise of temperature, it appears in general to be but little affected by change of uniform pressure. Likewise the effect of pressure upon viscosity and similar factors is in general unimportant as compared with the effects of temperature; for a change of a few degrees will exert as great influence upon this type of property of a condensed system as a pressure change of 1000 atm.

Closely allied to this is another point. The transformations of which we have been speaking are reversible, *i.e.*, they will go in either direction depending upon the conditions. But there are other transformations which are irreversible—they will proceed

[14] P. W. Bridgman, *J. Am. Chem. Soc.*, **36**, 1344 (1914).

in one direction only. As to these nothing can *a priori* be said; for such transformations take place whenever and wherever their rate becomes appreciable. Consequently the temperature region within which such an irreversible transformation takes place varies with the conditions, especially such as the presence of a solvent; but there is no reason to believe that pressure quickens this process at all. This conclusion is borne out by the fact that high pressure acting on either marcasite or aragonite has been found to be absolutely without effect in inducing the transformation to the more stable pyrite, or calcite, respectively.

On the other hand, pressure may induce some transformations which would not be predicted in advance of experiment. For example, B. H. Hite, working at the West Virginia Experiment Station, found that pressure alone will coagulate albumen, and that—possibly by reason of this coagulating power—it will kill bacteria, yeasts, molds, and other microörganisms. This striking fact may possess considerable practical importance, for, to take an illustration, it was found that a comparatively low pressure of 4000–5000 atmospheres applied for two minutes destroys every pathogenic organism in milk, without altering its odor or taste, though even the very delicate milk enzymes are not impaired.[15]

Hitherto we have considered the effect of pressure upon systems of a single component only—in other words, its effect upon what are usually looked upon as physical changes. Let us now take up very briefly condensed systems of more than one component. The simplest case of this character is the solubility of a salt in water. The influence of pressure upon solubility has been determined reliably only in a few cases, but the results agree in showing that the solubility is affected only slightly, so slightly indeed that the effect [16] is negligible as compared with that of tem-

[15] See the papers by Hite and collaborators: "The Effect of Pressure in the Preservation of Milk," W. Va. Expt. Station Bull. No. 58 (1899); "The Effect of Pressure on Certain Microörganisms Encountered in the Preservation of Fruits and Vegetables," *ibid., Bull.*, 146 (1914).

[16] The change of solubility with pressure at constant temperature $(\partial x/\partial p)$ and its change with temperature at constant pressure $(\partial x/\partial t)_p$ are related by the expression $\left(\frac{\partial x}{\partial t}\right)_p \Big/ \left(\frac{\partial x}{\partial p}\right)_t = \frac{\Delta H}{T\Delta V}$, where ΔH and ΔV are respectively the partial heat change and partial volume change accompanying the process of solution.

perature; for the solubility change, which may be either positive or negative, is of the order of 1 per cent. for 1000 atm. Corresponding to this, pressure has but a slight influence upon binary condensed systems generally, and upon the melting temperature and composition of the eutectic mixture in particular; this effect, indeed, is of the order of the present uncertainty in such observations at ordinary pressure, so that we have not yet been able to establish it definitely. That these influences should be small is manifest from the following reasoning. Any chemical equilibrium is determined by the relative concentrations, when a state of equilibrium has been attained, of the several molecular species concerned in the reaction; consequently the position of equilibrium is affected by pressure only in so far as the pressure alters the relative concentrations of the several reacting molecular species. Now since the compressibility of liquids and solids is small, the difference in compressibility (which is a measure of the effect of pressure in altering the relative concentrations) is very small, and consequently the effect of pressure is in such cases very small.

But the effect is of another order of magnitude when a gas or vapor is one of the components; for gases are enormously compressible and their reactivity is practically proportional to the pressure, *e.g.*, at 1000 atm. the concentration of a gas would be substantially 1000 times as great as at 1 atm. As a simple example, consider the amount of calcium carbonate (as calcite) which will dissolve in water enclosed in a vessel with a series of partial pressures of CO_2. The minimum solubility in water at 16° is about 16 parts per million, an amount which is quadrupled by the pressure of as little as 0.0003 atm. CO_2 (3 parts per 10,000, the proportion in outside air), and has increased 70 times when the CO_2 pressure reaches 1 atm. This great increase is an example of the very great effect producible by increase of concentration (partial pressure) of a gaseous component; it is, of course, due to the formation of bicarbonate in the solution, but this circumstance in no wise affects the force of the argument. And this effect is of an altogether different order of magnitude from that of hydrostatic pressure on solubility, the latter being negligible in comparison; and therefore it is manifest that in discussing such effects one must take care to observe whether the pressure is or is not changing the relative effective concentration of any of

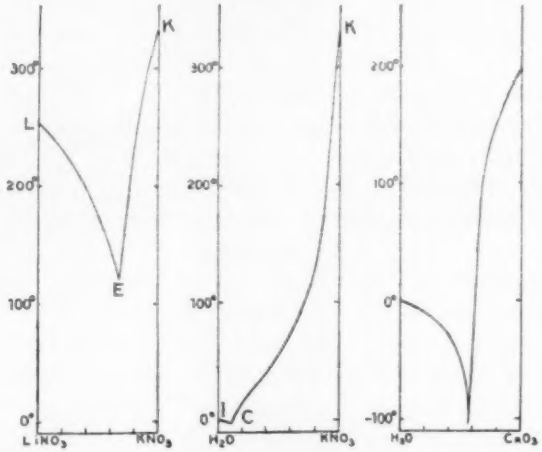
the components, a distinction which has not always been borne in mind by those who have considered such questions.

A closely related point is that a compound resulting from a reaction involving a volatile component will not be formed unless the concentration—in other words, the partial pressure—of that component is above a certain limiting value, this limit being dependent on the conditions, on the temperature in especial. An illustration may serve to make this clearer. If we wish to keep liquid water at 200° we must have it in a closed vessel capable of withstanding the vapor pressure of water at that temperature, which amounts to about 15 atm. (225 lbs. per sq. inch); likewise at 300° the vessel would require to be strong enough to support an internal pressure of 100 atm.; but if the vessel should leak, either because it was not strong enough or not tightly closed, the vapor would escape and the liquid water would disappear. Similarly we can keep $Ca(OH)_2$ as hydroxide at 550° in steam at 1 atm., but at 750° it would be necessary to have a pressure of water vapor of about 15 atm. (and at 950° about 100 atm.) if we wish to retain it all as hydroxide and to have no oxide present: in other words, if we should wish to prepare $Ca(OH)_2$ from CaO at a temperature of 750°, we could do so only by having continuously a pressure of at least 15 atm. of water vapor above it. A technical illustration of this occurs in the manufacture of salicylic acid, in which dry sodium phenolate is heated at 120°–130° in contact with a few atmospheres, pressure of CO_2, when the following reaction takes place: $C_6H_5.ONa + CO_2 \longrightarrow C_6H_4.(OH)COONa$, the yield being practically perfect; whereas, if CO_2 gas at 1 atm. pressure is used, a much higher temperature (180°–200°) is necessary and the yield is miserable. Nevertheless, there are a number of cases of this kind in which the effects have been attributed to pressure, whereas the real agent is the high temperature at which the process was carried on; in such cases the pressure plays a more or less subsidiary rôle, increasing the yield by securing an adequate concentration of the vapor.

Again, water vapor—or, for that matter, any volatile component—may, and does, act in a way precisely analogous to any non-volatile component, the only difference being that it in general requires pressure in order to hold it on the job, so to speak. As an illustration, let us consider the equilibrium diagrams in Fig. 6, I for the system $LiNO_3$–KNO_3, II for the system H_2O–

KNO_3, III for the system H_2O–CrO_3. In I L is the melting point of pure $LiNO_3$, which by admixture of KNO_3 is lowered along the line $L\ E$: this line therefore represents the equilibrium between solid $LiNO_3$ and liquid mixtures of $LiNO_3$ and KNO_3 of various compositions—in other words, it is the solubility curve of $LiNO_3$ in these mixtures. Similarly $K\ E$ represents the equilibrium between solid KNO_3 and liquid. These two curves meet in E, the so-called eutectic point, at which point (132°) a liquid of the composition 45 per cent. $LiNO_3$, 55 per cent. KNO_3

FIG. 6.



To show the similarity between the equilibrium diagram of the systems $LiNO_3$—KNO_3, H_2O—KNO_3, H_2O—CrO_3.

freezes to an agglomerate of the same composition. In II point I is the freezing point of water, and $I\ C$ the freezing point of solutions of KNO_3: in other words, $I\ C$ is the equilibrium line along which ice is in equilibrium with mixtures of H_2O and KNO_3 of various compositions. The line $K\ C$ represents the equilibrium between solid KNO_3 and mixtures of KNO_3 and H_2O; the end nearer C is the ordinary solubility curve of KNO_3 in water, while towards K it would be more logically called the solubility curve of H_2O in KNO_3. The two curves meet in C, which in the case of aqueous solutions is usually called the cryohydric point. These two systems are thus obviously altogether similar, the sole difference resulting from the difference in the vapor pressures of H_2O and $LiNO_3$ in relation to the prevailing

atmospheric pressure; namely, that whereas at the temperatures concerned the vapor pressure of $LiNO_3$ is inappreciable, that of water ranges from some millimeters up to many atmospheres. The equilibrium curve (III, Fig. 6) for the system H_2O–CrO_3 is included because in form it resembles very closely that for $LiNO_3$–KNO_3; the branch of the curve on the water side is much longer than in the case of H_2O–KNO_3, corresponding to the much greater solubility of CrO_3 in water at and below 0°.

At each point on the curve *C K* the liquid in equilibrium with solid KNO_3 has a definite composition and therefore a definite vapor pressure of water which must be maintained in order to secure the appropriate concentration. This vapor pressure becomes equal to 1 atm. at about 120° (the ordinary boiling point of a saturated aqueous solution of KNO_3); increases, as we ascend the curve, to a maximum, which in this case is only 2 or 3 atm., and finally decreases to zero at the point *K*. In systems such as this—namely, in which the liquid may have (under the appropriate conditions) any composition ranging from one pure component to the other—the magnitude of the maximum equilibrium pressure depends mainly on the melting point of the second component; where the melting point is low, as for KOH, the maximum pressure is less than 1 atm.; where it is high, as for potassium silicate, the maximum is some hundreds of atmospheres. Nevertheless, as is evident from the diagram, the lowering of melting point produced by a comparatively small amount of water may be quite large; for it would seem that a lowering of 100° could easily result from the presence of water vapor at pressures less than 20 atm.[17] The great similarity exhibited by these two systems shows that there is no real difference between melting curves and solubility curves;[18] a simple and well-known illustration of this is the fact that the melting point of $CaCl_2 6H_2O$ to a liquid of its own composition is merely a particular point on the graph representing the solubility of $CaCl_2$ in water.

[17] Incidentally it may be pointed out that the circumstance that pure water has a critical point at 370° and 200 atm. is of secondary importance in the discussion of systems belonging to this type. (See Morey and Niggli, *J. Am. Chem. Soc.*, **35**, 1089 (1913)).

[18] This point was clearly realized 30 years ago, by Guthrie, the first investigator of eutectics (*Phil. Mag.*, **18**, 117 (1884)).

In general it is much simpler to consider all such phase diagrams as solubility diagrams, as by so doing it is easier to grasp their full significance and to predict what will happen under specified circumstances.

This whole question of the state of equilibrium in systems containing a volatile component (water, in especial) is a very important one to geochemistry, and to ceramics in particular; but it would be beyond the scope of the present paper to go more fully into it. The available experimental data on this topic are somewhat scanty, partly because the experimental conditions have not been adequately controlled, partly because of the inherent difficulties; the latter, both on the practical and on the theoretical side, have now been largely surmounted. Let us again emphasize the importance of considering whether pressure is in itself the prime factor in inducing a particular change, or is merely subsidiary to the effect of the accompanying increased temperature—in other words, whether the new state is due to a displacement of the equilibrium consequent upon (a) a relative change of effective concentration produced by the pressure, or (b) the change of temperature in itself. In many cases it is difficult to unravel the effects of these two factors, as, for instance, in the production of gasolene from heavier oil at high temperature, or in the formation of a substance like anthracite[19] from cellulose and water at high temperature; and there is moreover always the possibility that we are not dealing with a real equilibrium at all, that the new state is the result merely of the increased rate of reaction induced by the higher temperature.

Hitherto we have considered only the effects of uniform, or pure hydrostatic, pressure; we shall now take up briefly the effects producible by non-uniform compression. This, which is equivalent to a stress (in many cases superimposed upon a smaller uniform pressure), is competent to produce results which may not be brought about by uniform pressure. It is, of course, applicable only to solids; nevertheless, one must watch for it in working at high pressures with systems containing originally a liquid phase because of the possible solidification of the latter under

[19] F. Bergius, *Z. Elektrochem.* **18**, 660 (1912); **19**, 858 (1913); *Engineering*, **96**, 262 (1913); "Die Anwendung hoher Drucke bei chemischen Vorgängen und eine Nachbildung des Entstehungsprozesses der Steinkohle's (pamphlet publ. by W. Knapp, Halle, 1913).

pressure.[20] In working with solids, therefore, one must distinguish carefully between these two; failure to observe this distinction has led to many apparently contradictory statements, and consequently to some confusion. The main difference is that whereas a homogeneous solid body recovers its original dimensions and properties when relieved from a uniform pressure, it is changed permanently by a stress in excess of its elastic limit; the residual effect is evident as a change of shape—a deformation—which is accompanied by a permanent change in several other properties, *e.g.*, in the case of metals, by residual changes in density,[21] strength, electrical resistance, thermoelectric power. That the effects of stress on a crystalline aggregate outweigh those of uniform pressure follows if we identify a deformation under stress with a real partial local temporary melting, on the basis that the stress acts upon the solid but not upon the liquid phase.[22] This hypothesis, which is not in conflict with any direct experimental evidence, serves to correlate a number of observations on the flow of metals and of other crystalline aggregates; a process essentially the same has in recent years been postulated by several English metallographers as a means of accounting for phenomena connected with the important question of the hardening of metals. In this connection it may be pointed out that the circumstance that a solid has been deformed indicates, not that its strength was necessarily small, but that the shearing forces to which it was exposed were great enough to overcome the resistance to deformation offered by the solid; in other words, the fact that a metal has flowed is no criterion of its strength, nor does it indicate that at the time of flow the metal was necessarily liquid as a whole. Indeed, by deformation of a metal its strength may be materially increased, as instanced by the comparative tensile strength of a wire and of the bar from which it was drawn; this circumstance is made use of in making vessels capable of withstanding the highest pressures.

[20] At ordinary temperature a heavy lubricating oil, such as is commonly used to transmit pressure, will become very pasty at about 4000 atm.; kerosene about 12,000 atm., and even gasolene at about 20,000 atm.

[21] See Johnston and Adams, *J. Am. Chem. Soc.*, **34**, 563 (1912); *Am. J. Sci.*, **35**, 206 (1913).

[22] This hypothesis, and some of its consequences, have been discussed in previous papers; see Johnston and Adams, *Am. J. Sci.*, **35**, 206 (1913); Johnston and Niggli, *J. Geology*, **21**, 599 (1913).

It would lead too far to go more fully into this interesting question, particularly as some portions of it are still in controversy; and indeed, they may remain so for some time, as it is very difficult to devise experiments along this line which shall be susceptible of definite quantitative interpretation. The distinction between uniform pressure and non-uniform compression remains, in any case; it may perhaps be emphasized by the fact that an explosive may be subjected to high hydrostatic pressure without exploding, though very little in the way of a stress may suffice to set it off.

This suggests another point upon which there has been some misapprehension. It has been asserted, notably by Spring, that pressure will cause the formation of chemical compounds and alloys from their constituents, *e.g.*, metallic sulphides from the metal and sulphur, etc. But in the first place, Spring's mode of compression was to consolidate the constituents by squeezing them and to file up the resultant block, repeating this process two or three times; and, in the second place, his criteria for establishing the formation of the compound were altogether insufficient. There is no question that a small amount of the compound was formed at the surfaces of contact, but this is not to be attributed to the pressure in itself but rather to the grinding process to which the material was subjected; indeed, the same effect can be more simply observed by grinding the materials together in a mortar—in many cases, merely by bringing them in contact. Again, with reference to the reputed formation of alloys by pressure, it has been shown that such "alloys" are merely agglomerates; and it appears that pressure can favor the formation of but one group of alloys, namely, by bringing into good contact two metals capable of forming solid solution, this process going on very slowly thereafter by diffusion of one metal through the other.[23] We believe, therefore, that pressure in itself does not favor the formation of alloys nor of compounds such as metallic sulphides; indeed, if anything, it hinders such interaction for it raises the melting point of all metals excepting bismuth. On the other hand, a grinding process will achieve results not producible by

[23] This whole question of the effect of pressure upon reactions between solids is treated at length in another paper; see Johnston and Adams, *Am. J. Sci.*, **35**, 205 (1913). With respect to the rate of diffusion in solids, see Van Orstrand, U. S. Geological Survey Prof. Paper 95 G. (1915).

uniform pressure, a fact consonant with the hypothesis mentioned above; for instance, calcium carbonate (calcite) ground in a mortar[24] loses a little CO_2, whereas there is absolutely no decomposition when it is subjected to high hydrostatic pressure.

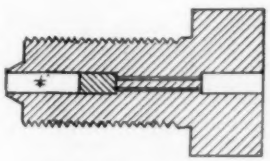
In concluding this sketch of the effects of high pressure let us look at the general type of apparatus required for high pressure work, and at the general mode of experiment. One may say that the main technical difficulties in experimental work in this field have now been successfully overcome—in particular it is a simple matter to obviate all leaks; nor need such work now be more costly than several other types of research work now carried on in many laboratories. It is, of course, not feasible to go into all the little details necessary to insure success, nor into all the variants used by different investigators, so that only the general features of the apparatus which we have used will be alluded to.

First, as to the method of measurement of pressure. Bourdon gauges can be obtained for any pressure range, though, if the range is large, they are not sensitive to small changes of pressure: moreover all of them are more or less subject to the disadvantage that they do not yield the same readings with decreasing as with increasing pressure. Nevertheless for many purposes they are quite suitable, if calibrated against an absolute gauge. The absolute gauge itself may be used; it consists essentially of a piston of known effective cross-section supporting a known weight, but in many lines of experiment it is inconvenient because each movement of the piston is accompanied by a change of volume which, if not compensated, causes change of pressure. The most convenient method of pressure measurement in experimental work is to utilize the fact (first observed by Chwolson in 1881) that pressure affects the electrical resistance of metals, the changes being perfectly reversible and reproducible if the coil of wire has been properly seasoned beforehand; the effect is positive with some metals, negative with others, and so cannot be due merely to the diminution of volume with increase of pressure. The most

[24] It may be pointed out that very large momentary stresses can be produced when material is ground in a mortar; for 10,000 atm. corresponds to only 1 kg. on an area of 0.0001 sq. cm., equivalent to a square of side 0.1 mm., so that under such circumstances this amount of compression may readily be exceeded momentarily.

suitable material for the coil of such a pressure gauge is either manganin or therlo, by reason of their very small temperature coefficient at ordinary temperatures; the magnitude of the effect with a 100 ohm coil is about 0.2 ohms per 100 atm., so that one may readily secure a sensitiveness corresponding to differences of 0.1 atm. The readings of such a gauge show no noticeable time-lag and are independent of the direction from which the pressure was approached. The gauge is calibrated [25] by taking readings at a number of settings of the absolute gauge; the calibration curve is very nearly a straight line at lower pressures, and altogether straight at higher pressures, so that it can be used with some confidence for extrapolation. Its absolute accuracy is limited by

FIG. 7.



Pressure gauge. The coil (not shown in the figure) sits within the cylindrical hole at the left; the wires pass out through the block of soapstone or marble.

that of the absolute gauge; by this means therefore pressures can be determined with all the accuracy necessary. In the actual form of gauge which we have used the coil is set in a cylindrical hole cut in a steel piece, such as is shown in Fig. 7, fashioned so that the gauge may be screwed in at any one of a number of interchangeable positions in the apparatus; the connecting wires are led out through either soapstone (for lower pressures) or marble (for the higher pressures), an arrangement which is both pressure-tight and electrically good.[26]

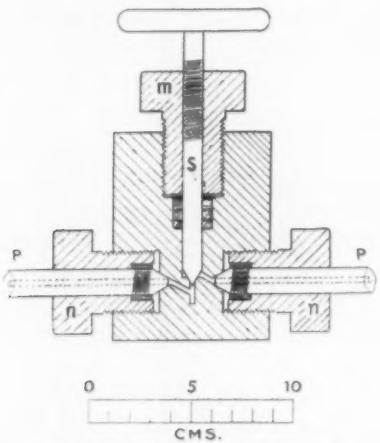
Pressures up to about 2000 atm. can be developed by means of a simple pump; by combination of such a pump with a multiplying

[25] Or it can, of course, be calibrated at a number of previously determined points, *e.g.*, melting pressures of pure substances; this procedure being precisely analogous to the calibration of any form of thermometer at a series of melting temperatures previously fixed by means of a gas thermometer.

[26] An alternative mode is described by Bridgman, *Proc. Am. Acad.*, **49**, 640 (1914).

device,[27] pressures up to 5000 atm. can be developed, this being the limiting pressure of the steel tubing that transmits the pressure to the reaction vessel. Pressures higher than this are best developed within the vessel itself by means of a plunger actuated, preferably, by a hydraulic press; and it is well not to have the hydraulic press too powerful, as otherwise it is too easy to burst small pressure bombs, *e.g.*, for a bomb with a hole ½ inch in diameter, each ton of thrust exerted by the press corresponds to a pressure of about 1000 atm. within the bomb.

FIG. 8.



Details of high pressure valve and connections, drawn to scale. The main body of the valve is of best quality nickel steel. The conical lower end of the valve spindle *s* fits into a conical depression. The leather packing around the spindle is held down by the nut *m*. On either side of valve is shown the type of high pressure connection which has been used for joining various parts of pressure apparatus. The end of the pressure pipe *p* is turned off at 60° and fits pressure-tight into a conical depression. A small round nut is screwed onto the end of the pipe and the whole is held down tight by means of the larger nut *n*.

Fig. 8 illustrates the type of valve which we have used, and the mode of making connections. The valve-stem *s*, which ends in a cone fitting into a conical depression in the valve block, is kept in place by the nut *m*. The packing consists of three layers of leather surmounted by a steel disk. The pitch of the screw between stem and nut is identical with that between nut and block;

[27] This consists essentially of a thick-walled cylinder, with a larger axial cylindrical hole at one end than the other, each provided with a tight fitting piston, the two pistons being connected together; by this means the pressure developed at the small end is proportionally greater than that at the large end in the ratio of the effective areas of the two pistons.

by this means one can tighten the nut *m* without jamming the valve down into its seat. The high-pressure connection, which has proved uniformly satisfactory for making all the connections required, is made as follows: The end of the pipe *p* is turned off at an angle of 60°; a small rounded nut with left-handed thread is put on, and the whole held in place by means of the large nut *n* which is undercut to receive the smaller nut. The end of the pipe fits into a conical hole also turned at an angle of 60°; the tip is left, or made, very slightly larger (either by not turning it down completely, or by upsetting it by means of a hammer), a detail which has the effect of insuring that when the end of the pipe is forced into its seat by screwing up the nut *m*, it is the extreme tip that binds on the surrounding metal. This type of joint may leak when pressure is applied for the first time; increase of pressure, however, makes the joint tight by expanding the tip of the tube against its seat, and when this has once happened, the joint remains tight indefinitely. This type of joint possesses the advantages: (1) That it may be taken apart and put together again repeatedly without impairing its efficiency; (2) that it is tight every time and thus obviates troublesome delays due to leaks; (3) that the danger of the whole joint blowing out at high pressure—which may easily happen with ordinary butt joints—is practically obviated, because of the smallness of the bearing surface under all conditions. Moreover all joints are completely interchangeable, and any one of them may be closed off entirely by inserting, in place of the tube, a solid piece of steel similarly fashioned with a shallow small hole drilled axially at its conical tip.

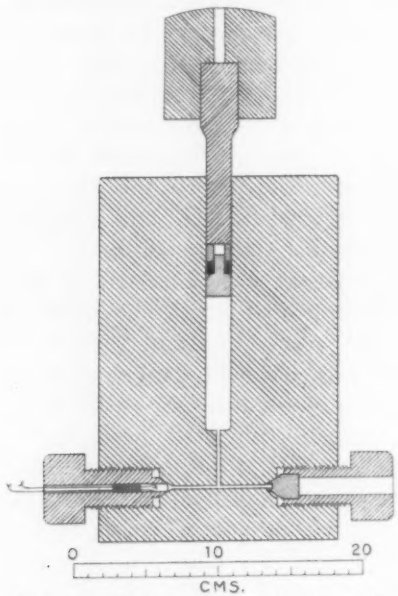
This type of connection and of plug is also illustrated in Fig. 9, which is a sectional drawing of a bomb used for work at high pressures, with the steel piece (Fig. 7) carrying the pressure gauge in place. The essential feature of this bomb, which is copied from Bridgman,[28] is its absolute freedom from leaks at all pressures; this is achieved by the use of a piston so constructed that the effective hydrostatic pressure upon its packing is always greater than that which it is required to hold,[29] and by previously seasoning the bomb in such a way that the hole remains of sensibly

[28] Bridgman, "The Technique of High Pressure Experimenting," *Proc. Am. Acad.*, **49**, 627 (1914); q. v.

[29] This is, of course, the principle underlying all successful packings.

the same form and dimensions throughout the pressure range. This is secured by boring a hole, about 1 mm. less in diameter than the final hole is to be, in the block of steel (previously properly heat-treated), making an appropriate plunger, filling the hole with kerosene, and developing within the bomb a pressure of 20,000 atm. or more; by this procedure the hole is bellied-out, the steel deformed and thereby strengthened,[30] so that when

FIG. 9.



Sectional drawing of bomb for high pressures, with leak-proof plunger. The pressure gauge is shown in position at the left; the connection towards the right-hand side is closed off.

the hole is reamed out to its final diameter, the bomb is capable of withstanding satisfactorily repeated applications of pressure of 10,000 atm. or more. The leak-proof piston consists of a hardened steel piece (which fits the hole nicely), surmounted successively by washers of rubber, copper, soft steel and a hardened steel collar which is in contact with the solid plunger actuated by the press; by means of this construction the total thrust exerted by the pressure within the bomb is taken up by a washer of smaller

[30] I understand that this fact of the strengthening of metal by deformation is taken advantage of in the manufacture of the cylinders for the Ford engine.

area, wherefore the hydrostatic pressure upon the washer is always greater than that within the bomb and no leak of the contents occurs. As an illustration of the absolute tightness of this type of piston, it may be mentioned that the plunger, at a pressure of 2500 atm. within the bomb, returned to the same position within 0.02 mm. when the pressure had been raised beyond 8000 atm. and lowered again to 2500 atm.

For any work at high pressures a previous seasoning of the bomb at a pressure higher than is to be used in the experimental work is essential; without it, there is a partially non-elastic yielding of the metal and therefore a constant liability to leak. With a properly seasoned bomb, a simple rubber washer as packing for the solid plunger suffices for many purposes in which absolute freedom from leak is not essential, *e.g.*, for seasoning the coil of the pressure gauge by exposing it to a pressure in excess of the maximum in its subsequent use. With a seasoned bomb there is a slight elastic reversible yielding with pressure; thus we observed that a cylindrical steel bomb, 4-inch external diameter and 1-inch hole, increased in external diameter about 0.001 inch for each 1000 atm. pressure developed within it.

With apparatus such as has been adverted to, one is now enabled to determine many constants with just as great accuracy at high pressures as at ordinary pressure, *e.g.*, any change which can be recorded by electrical means,[31] or a volume change or a melting, provided that the corresponding temperature is not too high. But if the temperature in question is higher, the metal begins to lose its strength, and the apparatus must be constructed in such a way that the temperature is developed inside the bomb, the walls of which are kept cool. This necessitates a fairly large opening to admit of the electric furnace and heat insulating material, and consequently requires a powerful press to hold the lid on; for instance, if the central hole is 2-inch diameter, and the pressure within it is 2000 atm., the counter-thrust which must be exerted by the press is about 100 tons.

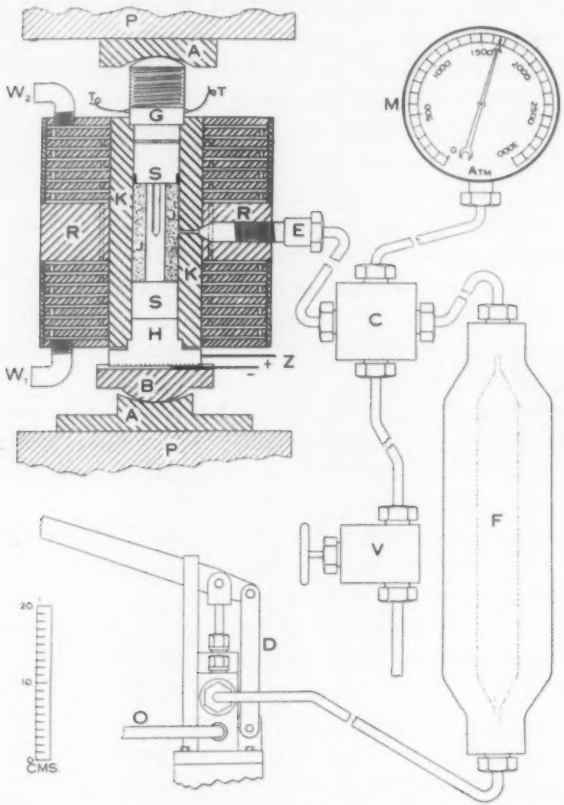
Fig. 10 shows the general arrangement of apparatus[32] with which the melting curve of certain metals up to 2000 atm. was

[31] Wahl has by direct optical observations made determinations of physico-chemical constants at high pressures. (*Phil. Trans. Roy. Soc., London*, **212 A**, 117 (1912)).

[32] For details, see Johnston and Adams, *Am. J. Sci.*, **31**, 501 (1911).

determined; and Fig. 11 represents the central portion of the bomb. The only point to which we shall advert is the method

FIG. 10.

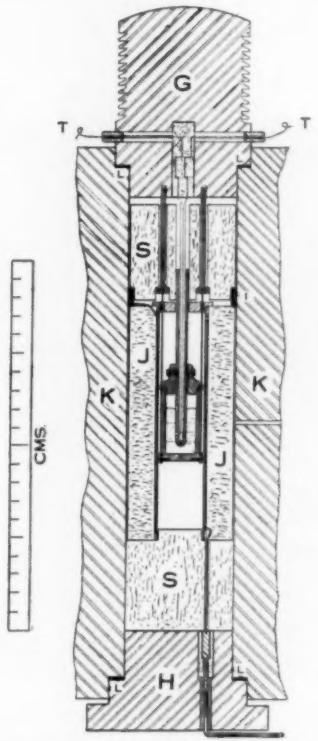


General arrangement of apparatus. The bomb is drawn to scale; the rest of the apparatus only approximately so. Pressure is supplied by the pump *D*, and transmitted through the system by means of a paraffin oil which has at the same time a high boiling point and low viscosity. *F* is a steel bottle of about one liter capacity; it serves to increase the volume of the system. The valve *V* (shown in detail in Fig. 8) is used to lower the pressure in the system. *M* is a Bourdon gauge graduated to 3000 atm. in divisions of 50. The connection block *C* affords a 4-way connection between pump, valve, gauge, and bomb. The latter consists essentially of a ring of nickel-steel *RR*, and a number of rings of boiler plate shrunk on to a cylinder of steel *KK*. On the outside of the rings is shrunk a thin cylinder. The cooling water enters at W_1 and leaves at W_2. The bomb is closed by means of the steel plugs *G* and *H*, which are held in place by a hydraulic press the platens of which are shown at *PP*. The curved surfaces of *A* and *B* on one end and of *A* and *G* on the other constitute the essential parts of the device used for securing alignment of bomb and plugs. *JJ* is the electric furnace (for details see Fig. 11), and *SS* soapstone blocks for thermal insulation at the ends. Thermocouple wires are shown at *TT*, and heating current wires at *Z*.

of closure, which again depends upon the principle of having the packing material subjected to a higher pressure than that within the bomb; this is secured again by concentrating the thrust upon

a smaller area. It is effected by making the plug (G or H) of the shape shown and a good fit, and imprisoning the copper washer LL between plug and bomb; this copper washer, which manifestly bears the whole thrust, fills up the space allotted to it

FIG. 11.



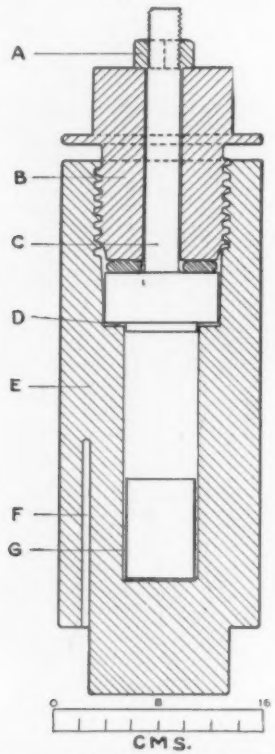
Electric furnace and interior of bomb, drawn to scale. *JJ* is the furnace, *SS* soapstone blocks for thermal insulation of the ends, and *G* and *H*, the plugs which close the bomb. Freedom from leak is insured by the use of the rings or "washers" of sheet copper imprisoned at *LL*. Thermocouple wires *TT* are led into the bomb through the upper steel plug *G*. One terminal of the heating circuit is grounded onto the bomb at *I*, the other passes out insulated through *H*. The graphite crucible with thermocouple tube in place is shown suspended from the upper plug.

but cannot flow away. This type of joint is absolutely tight and has been used in many hundreds of experiments.

For work at temperatures higher than about 400°, oil can no longer be used as the fluid for transmitting the pressure, and one must have recourse to a gas. To work with a gas is much more troublesome than with a liquid, by reason of the very great compressibility of the gas; incidentally the chance of explosion

and the damage likely to ensue are very much greater. Several writers [33] have described apparatus which enabled them to reach temperatures of 1000° or higher at considerable pressures (up to 1000 atm.); but for work at high temperatures with high concentrations of water vapor we have found it more convenient

FIG 12.



Drawing of type of bomb used particularly for work with systems alkali—silica—water at temperatures up to 750°. The essential feature is again the leak-proof closure, achieved by means of the copper ring imprisoned at *D*. *F* is a small hole for the insertion of the thermo-element; *G* is a gold crucible to contain the charge.

to proceed in another way, namely, to enclose the other materials with a definite amount of liquid water in a leak-proof bomb which is then heated to the desired temperature long enough to insure the attainment of equilibrium, chilled rapidly and the charge

[33] *e.g.*, Hutton and Petavel, *Phil. Trans. Roy. Soc. London*, **A**, 207, 421 (1907); H. C. Greenwood, *Proc. Roy. Soc., London*, **A**, **83**, 483 (1910); Haber, *Z. Elektrochem.*, **21**, 89 (1915).

analyzed. For such work, *e.g.*, in investigation of the systems $RO–SiO_2–H_2O$ (where RO represents an alkali or alkaline earth)—it is at the present time more important to map out the whole field than to determine absolutely the coördinates of any one point; the pressure, which is regulated by varying the amount of water, need not be known accurately, though it must be definite, thus necessitating that the bomb be absolutely free from leak.

FIG. 13.

General view of apparatus, showing the pump for the hydraulic press, the high pressure pump, and, on the board, the valves, gauges, etc. In the left background one of the bombs and a small part of the press are visible.

Fig. 12 shows the type of bomb [34] which has proved very successful. Such bombs have been used for several hundred experiments at temperatures up to 500°, at which temperature they will hold in pressures in excess of 500 atm.; and numerous experiments have been carried as high as 750°, with pressures in excess of 100 atm. The essential feature is the closure, which is similar to that already described; the general features of the bomb are manifest from the figure.

Figures 13 and 14 illustrate the general set-up of our apparatus.

[34] For details see Morey, *J. Am. Chem. Soc.*, **36**, 215 (1914).

RECAPITULATION.

In conclusion, may I recapitulate the points which I have endeavored to bring to your attention. In the first place, chemistry hitherto has been occupied very largely with a very restricted range of conditions; for a complete knowledge of the subject it is requisite that the properties of substances be investigated

FIG. 14.

Showing the press and accumulator; and at the right the absolute gauge.

throughout the range of temperatures and pressure within which each substance can exist. A promising way of investigating the mechanism of certain processes—*e.g.*, the passage from solid to liquid state—is to ascertain the effect of pressure as well as of temperature upon the process; indeed in many cases these two factors cannot be varied independently of one another. Pressure and temperature are completely analogous as variables, though in general a pressure change of 1000 atm. will produce no larger effect than a temperature change of a few degrees.

Pressure raises the melting-point of solids (with two known exceptions, ordinary ice and bismuth), the change being successively less with each increment of pressure; but there is no evidence at all for a maximum melting-point or for a critical end-point. Indeed all evidence indicates that by the application of *sufficient* pressure gases would be transformed to solids, a conclusion which is in harmony with that reached on other grounds that the interior of the earth is solid. The effect of pressure upon solubility, and upon condensed systems generally is small; when a gaseous component is present the effect may be very large by reason of the great increase in concentration of the gas produced by the pressure. But many of the effects which have been attributed to pressure are not due to it alone, but often to the high temperature chiefly, the pressure being merely a subsidiary influence; and in such discussion one must always be careful to distinguish between uniform pressure and non-uniform compression as the latter will produce effects very different from those of the former.

Many physico-chemical determinations may now be made with just as great accuracy at high pressures as under ordinary conditions. Apparatus suitable for this purpose has now been developed in several laboratories; some of the apparatus which we have used is illustrated and briefly described.

Nitrate Deposits Disappointing. ANON. (*U. S. Geological Survey Press Bulletin*. No.297, November, 1916.)—Nitrate deposits in many parts of the United States have been examined during the last two years by the United States Geological Survey, Department of the Interior. The importance of finding a natural supply of nitrates within our own borders, which might serve our needs in case of war, has given incentive to this work and has directed widespread public attention to the subject.

Prospectors in many places have raised great hopes by finding good surface showings of these salts, but investigation has seemed to force the acceptance of a general adverse judgment as to their value—a judgment that has been adopted with the greatest reluctance by all concerned. Incidentally, advantage seems to have been taken of the situation to promote certain stock-selling enterprises, even after the evidence as to the worthlessness of the deposits became sufficient to satisfy any competent judge, so that one is forced to question either the good faith of the promoters or their practical judgment.

As a result of careful study of these deposits, and particularly of evidence gathered on recent visits to prospects in different parts

of the country, Mr. Hoyt S. Gale, a geologist of the Federal Survey, has submitted the following general summary, which is commended to the consideration of those who are tempted to invest their money in such enterprises.

Fine specimens of practically pure nitrate of soda and nitrate of potash (saltpeter) have been found in many parts of the country, and careful investigation of specimens and localities seems to warrant some definite conclusions as to the practical value of these deposits, especially to those who are invited to spend their money in investigations like those the Survey has already made.

The nitrate salts occur as crusts or films on the faces of ledges; as seams—most of them thin, though some are fairly thick—in crevices of shattered rock; and as deposits filling spaces in porous rocks at and near the surface or extending to a depth of several feet. They are naturally preserved in recesses in the rock ledges, where they are sheltered from the dissolving action of rain, snow water, or even mist. They are found in lava ledges, in beds of volcanic tuff or ash, and in limestone and sandstone. Their existence or preservation is apparently dependent rather on the shattered or porous nature of the rock than on its kind or composition. These deposits, which have been referred to as cave or ledge deposits, are of essentially the same type wherever found, although they vary considerably in details of occurrence.

The incrustations are found not only on the faces and fractures of ledges of solid rock, but some of them form layers or cementing constituents in the loose soil and rock breccia at the bases of cliffs, or lie in places protected from the weather. Some samples obtained from both sources are rich in nitrate salts, and analyses of such materials will bear little significant relation to the actual character or content of the mass of the rock of which the ledge is formed. It appears that the deposits are surficial—that is, they do not extend far into the mass of the rock—and the nitrate salt found is insignificant in amount.

Nitrates are found in unusually large quantities in some soils and in some clay hills, particularly in southern California. These deposits have been examined by many persons and the general conclusion reached has been unfavorable to the idea of their practical utilization. The nitrate content, although unusually large as compared with the content of ordinary soils, probably does not average over 1 or 2 per cent. of the soil or clay, and it is very doubtful whether the material could be worked commercially.

Any one who is not convinced by the judgment already reached as to these deposits and who is determined to devote his time or money to their further exploration should do so with full knowledge of the evidence already in hand and should not be led into such a venture by more or less misleading representations. The Geological Survey will always be glad to make an examination of any samples submitted.

SCIENTIFIC RESEARCH FOR NATIONAL DEFENSE AS ILLUSTRATED BY THE PROBLEMS OF AERONAUTICS.*

BY

LIEUT.-COLONEL GEORGE O. SQUIER, SIGNAL CORPS, U. S. A.,

Member of the Institute.

THE following are some present problems connected with the development of Military Aviation and Aerostation:

I. AERODYNAMICS.

(*a*) Continue the development of the mathematical theory to explain the phenomena recorded in the aerodynamical laboratories, and to forecast further results.

Determine the value of numerical factors for correcting the coefficients observed in tests of small scale models at low air speeds in wind channels in order that these coefficients may be applied more accurately in the design of full scale airplanes.

(*b*) Obtain solutions for the speed and direction of flow of air about geometric and aerotechnic forms, and develop experimental means to visualize or map the speed and direction of flow.

(*c*) Map the currents of the upper atmosphere which may be of most use in aerial navigation, and evolve simple practical rules for the guidance of pilots.

(*d*) Give fuller explanation of the phenomena of soaring, *i.e.*, airplaning indefinitely without motive power.

(*e*) Develop equations and laws of comparison by which the behavior of large aircraft may be more accurately foretold from tests of models. Apply further the principle of dynamical similarity.

(*f*) Investigate more direct and effective methods of securing a lift or thrust in the air from the consumption of fuel.

(*g*) Complete theory of the air-screw.

II. ENGINE PROBLEMS REQUIRING RESEARCH.

(*a*) *Fuel.*—Possibly the most far-reaching problem is fuel. A fuel that will carry more power into an engine per unit volume will be a direct gain.

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* Abstract of an address before the National Academy of Sciences, Boston, Mass., November 14, 1916. Communicated by the Author.

Attempts have been made to combine alcohol, gasoline, acetylene, picric acid, ether, and other hydrocarbons with the above object in view. Questionable results have followed. There has been an increase of power, but nothing so far commercially or practically useful.

This question must be studied with the greatest of care and from a truly research standpoint.

(*b*) *Solid Fuel.*—Solid fuels that can be converted into liquid in small quantities just prior to use are desirable for military aviation. In case of accident from shot or shock, leakage of liquid fuel is a danger. Solid fuel could be carried in quantity with less danger.

(*c*) *Engine Cooling.*—The problem of radiation is important. If some substance could be found that would circulate through the cooling system, at higher temperatures than water, it is probable that greater engine efficiencies would result. Oils, salt waters and other materials have been tried with indifferent success.

(*d*) *Liquid Fuel Pipes.*—Tubing that will resist vibration (causing rupture) is desired. An oil- and gasoline-proof rubber tubing is reported as used in Europe. This development is highly important, not only for tubing, but for containers in which to carry liquid fuel. Some sort of fabric and rubber tank that would really resist the action of gasoline would be of the highest benefit.

A difficulty lies in the fact that the tanks are large (say 20- to 100-gallon capacity). The structural problems would be serious. The tanks now used are large and of metal. Vibration causes much difficulty and leakage.

(*e*) *Metal Coating.*—The protecting of the metal parts of an airplane, especially the fittings and cables, is a serious problem. A material is desired that would really prevent dangerous corrosion. Nickel plating over copper is very good, but will not suffice. Rust strikes through very rapidly. Baked enamel is the best coating. It is impossible to apply in many cases.

(*f*) *Sound.*—The question of eliminating the noises involved in the operation of aircraft is one of importance. The peculiar note of the propeller of a Zeppelin can be heard for several miles, and is usually the first warning of its approach at night.

III. MISCELLANEOUS.

(*a*) *Physiological.*—Study the physiological and psychological effects of low density air at high altitudes on the performance of pilots.

(*b*) *Transparent Wing Covering for Airplanes.*—A wing covering which would answer the following general requirements would be of great value to military aviation:

Weight not more than five ounces per square yard.

It should present reasonably great resistance to flame.

It should be reasonably proof against action of salt water, moist air, extreme dryness and quick temperature changes.

It should not stretch in any direction. Its ability to retain original form as placed on the airplane is very important.

It should have tensile strength of at least 75 pounds per inch width in any direction.

Its tendency to tear and split because of tack holes through it, or because of bullet holes, should be as small as possible.

(*c*) *Development of Light Alloys for Airplane Construction.*—Pure aluminium or aluminium alloys. It is believed that a great deal can be done in this direction. So far no alloy has been developed, except possibly in Germany, which can compare with average Alaskan spruce in its "specific tenacity."

(*d*) *The Structure of Gusts.*—It is believed that this is of sufficient importance to aviation to warrant considerable expense in its study.

Painstaking investigation of the character of eddy formations caused when wind strikes trees, hollows, cliffs, etc., and the character of disturbances created by canyons, swamps, deserts, etc., would be of great value to aviators.

This can be done not only by smoke and toy balloon work in the vicinity of obstructions such as the above, but also by photographic work in wind channels.

A set of simple rules laying down just what the aviator may expect on one side or another of canyons, cities, trees, lakes and swamps would be very helpful in aviation.

(*e*) *Radio-apparatus for Aircraft.*—The subject of radio-intercommunication between aircraft in flight, and between aircraft and the earth requires for its solution the highest possible efficiency and reliability combined with minimum weight.

A present tendency is to entirely separate the power plant from the main engine of an aircraft. The generator body in this case has a stream-line figure and a separate small air-screw is provided. Among other methods the oscillion is being tried as the actual source of continuous electromagnetic waves.

(*f*) *Automatic Devices for Controlling Airplanes.*—The development of large airplanes, with great moments of inertia, has made necessary apparatus which will maintain the airplanes in a stable condition of flight. The basic principle of design of such devices should be such that reactions derived from any disturbance of the airplane from its normal or desired attitude with respect to the relative wind, and with respect to the earth's horizon, will, through the operation of the automatic controlling mechanism, cause the control surfaces to create moments which will return the airplane to its original state of equilibrium. It is suggested that the principle of flight is such that the lateral control (for oscillations about the X-axis), especially, should be automatic.

(*g*) *Bullet-proof Gasoline Tanks.*—Development of a material with which to line or construct tanks to contain the gasoline in an airplane in which a bullet hole will quickly close, entirely or partly at least. This would enable many a flier to get back to his own lines after having been fired upon.

(*h*) *Development of a Fabric as Good as, or Better Than, Irish Linen, for the Covering of Airplanes.*—There has not been manufactured in this country a fabric suitable for use in covering airplanes.

The fabric should answer all requirements laid down under *Transparent Wing Covering,* and be, in addition, such as to shrink the proper amount without harm when cellulose solution is applied.

It is possible that long fiber cotton might be developed that would answer the purpose.

We must become independent in all lines affecting our military aviation. To-day we depend entirely upon Ireland and England for our linen, and the supply is becoming very low in this country.

(*i*) *Aviators' Clothing.*—Much is still to be done in devising non-inflammable and protective clothing for aviators. This question is intimately connected with personal armor and safety in case of fall.

(*j*) *Ground-speed Indicator.*—An instrument which would

measure the actual speed of an aircraft over the ground would be useful in the operation of military machines.

(*k*) *Photography.*—The further development of the use of photography from aircraft offers one of the most promising fields of usefulness. A present tendency is to replace manual sketching of trenches, roads, etc., by a series of photographs taken at regular intervals from the moving airplane.

IV. PHYSICS OF THE AIR.

(*a*) *High Frequency.*—At present we have no evidence of vibrations in the air much greater than 40,000 to 60,000 cycles per second, but there is no reason to deny the possibility of vibrations of 100,000 to 200,000 or even a million cycles per second in the ordinary air we breathe. If these vibrations exist, may not they have an important function to perform in nature? The reason, of course, we do not perceive them if present, is because they are above the upper limit of the human ear, and also do not directly affect any of our other senses. Although, in general, viscosity would operate to rapidly damp out these high vibrations, yet the real nature of viscosity at extreme high frequencies is not sufficiently understood at present to be dogmatic. The present efforts of the Master Physicists in regard to the constitution of matter should before long make the securing of high frequency data in air of importance.

Electromagnetic waves of these frequencies existed through all time unperceived until Hertz devised a "detector." At present the detector for high-frequency air vibrations is the manometric flame, and it would be of great importance to invent a detector for air vibrations which would indicate their presence or absence up to 500,000 or a million per second. If we had such a "detector" and also means for producing such vibrations in air, it would be possible to provide a system of intercommunication, over short distances at least, based upon ultra-audible sound waves. We could, for instance, devise a noiseless foghorn as an aid to navigation.

(*b*) *Elasticity.*—The elasticity of the air has been made to serve in a great variety of machines to perform useful work. The original dynamite gun of Zalinski utilized the elasticity of compressed air as the explosive for propelling the projectile.

The best condensers for radio-telegraphy employ air as the dielectric. Any break-down automatically repairs itself and thus adds greatly to reliability.

The passenger automobile itself has been made possible by the development of the pneumatic tire.

(*c*) *Friction.*—The magnitude of the friction of the air against the surface of bodies moving through it may absorb large amounts of energy. The average velocity of shooting stars is 25 miles per second. They vary from 10 to 30 miles a second. The earth's orbital velocity is about 19 miles a second. It is sometimes added and sometimes subtracted from the shooting star's velocity according to the way the body enters the atmosphere. The friction of the air at these velocities is so great as to volatilize metals.

A mass of one gram of air moving with this velocity, 25 miles per second, has a kinetic energy of 8.0937×10^{12} ergs, which is sufficient to lift one ton of matter, 2000 pounds, to a height of 298 feet above the earth's surface. One gram is a small piece of matter to possess this potentiality. This enables us to comprehend, in part at any rate, the disastrous results of the cyclone, where houses and forests are bodily cut down as by a giant steel knife.

(*d*) *Mass.*—A cubic foot of air at 0° C. and 76 cms. pressure weighs .08071 pound, according to Rayleigh. A room $18 \times 20 \times 10$ feet contains 3600 cubic feet. The air in it, therefore, weighs 290.556 pounds. In liquid or solid form this air could be removed from the room with difficulty by a strong man.

On this view it appears that we have been passing our lives on the bottom of a deep ocean of comparatively heavy fluid, and that only recently have we learned how to utilize the dynamic reaction of this fluid to construct machines for transportation freely in three dimensions in the interior of this ocean. Who among us is wise enough to foretell what these machines may yet accomplish?

THE CHARACTERISTICS OF IRON IN HIGH FREQUENCY MAGNETIC FIELDS.*

BY

RALPH BOWN,

Department of Physics, Cornell University.

THE use of iron magnetic circuits in ordinary electrical generating and transmitting apparatus is so advantageous or more exactly so necessary, that it is at least mildly surprising to find that iron is in many cases worse than useless in high frequency magnetic circuits. So puzzling has been the behavior of the iron under these latter conditions that it has been made the subject of many researches in the past twenty years. Recently the writer took occasion to look up the literature of this research work and found it so extensive and widely spread as to merit the brief compilation which is presented below. The various researches have been considered in a consecutive, semi-historical order and wherever it was convenient the words of the original author have been used. In such cases quotation marks have been placed around the part which is copied verbatim.

The object of the paper is not particularly to comment on the value of any of the work which is cited, nor yet to criticize the conclusions drawn therefrom, but to present a digest of the most important publications which have dealt with the behavior of ferro-magnetic materials when subjected to the influence of high frequency alternating magnetic fields and to point out the more valuable and interesting of the results and conclusions. In a brief summary at the end of the paper the subject is reviewed in a collective way which may be of particular interest to the hurried reader.

THE FIRST EXPERIMENTERS (1827-1900).

As far back as 1827 it was noticed by Savary [1] that a steel needle was magnetized when in the neighborhood of the discharge current of a leyden jar. This was probably the first observation of the effect of an oscillating field on a magnetic material. How-

* Communicated by Prof. Ernest Merritt.

ever, the discharge of the leyden jar was not recognized as oscillatory until in 1842 Joseph Henry [2] demonstrated that needles magnetized by similar discharges varied not only in strength but in polarity as well. The range of electrical knowledge widened so fast in the following years that it apparently interested no one to think further on so relatively unimportant a detail as this "anolomous magnetization" of Henry's until Hertz,[3] in 1888, voiced his views on the matter by saying, with regard to some metal wires which he was using in experiments with very high frequency currents, that iron wires were no exception to the general rule and that the magnetic properties of the iron did not come into consideration with such high frequency oscillations. In the particular experiments of Hertz this was doubtless true, but that the conclusions had no general significance was indicated when J. J. Thomson [4] and some others, in 1891, showed that iron in a rapidly oscillating field absorbs energy which can only be accounted for as a magnetic hysteresis loss, and Trowbridge [5] also in 1891, expressed the opinion drawn from his work that iron is magnetized by high frequency oscillation and that the resulting energy loss increases the damping of the oscillating circuit. Probably this belief had prevailed for some little time in certain quarters, for a theoretical formula was published by Lord Rayleigh [6] in 1886, and by Stefan [7] in 1890, by means of which the high frequency permeability of iron wire could be calculated from separate measurements of its resistance to high frequency and to continuous electric currents. Using this formula as a tool experimenters set out to determine the values which the permeability assumed at various frequencies.

The first of these observers, Birkeland [8] (1893), records his conclusion that "μ decreases with the period of the oscillations." In a more extended investigation in 1893, Klemencic [9] used Rayleigh's and Stefan's formula in the following form:

$$\omega' = \omega \pi a \sqrt{\frac{n \mu}{\sigma}}$$

where ω' = the high frequency resistance, ω = the continuous current resistance, a = the radius of the wire, σ = the specific resistance of the wire, μ = the magnetic permeability, and n = frequency. From measurements made at a frequency of 9×10^7 cycles per second, and with a field intensity "H = 290 Abs. E.,"

he calculated that μ was 118 for soft iron wires 0.452 mm. in diameter. Slightly later, in 1898, Klemencic [10] published some work on core losses at high frequencies from which the conclusions are somewhat indefinite.

C. E. St. John [11] (1894) compared the self inductions of similar iron and copper circuits and thereby showed that μ must be quite large even for very rapid oscillations. The fact that the high frequency magnetization curve, or the relation between B, the instantaneous flux density and H, the instantaneous field intensity is not a straight line and that therefore average values of μ obtained by experimental methods will depend on the field intensity as well as on other factors, was indicated when Marchant [12] (1900) discovered that the period of an oscillating circuit containing iron varies as the oscillations die out. Marchant believed that this variation of the period was due to the change in the value of μ as H passed through smaller and smaller values and later (1903) he published [13] a graphical method of determining the curve of the oscillatory discharge from a condenser, through a coil embracing iron, when the B-H curve of the core was known.

Before going farther we may briefly mention the Marconi Magnetic Wireless Detector which was announced by Marconi [14] in 1902. In this well-known instrument the received high frequency currents were caused to act magnetically on a piece of laminated soft iron which was continually going through a very slow magnetic cycle. The high frequency magnetic impulses seemed to have the power of altering the shape of the B-H curve for the slow cycle so that the arrival of a wireless impulse was registered by a sudden change of flux in the iron of the detector, which produced an E. M. F. in the recording circuit. Experiments by Piola [15] (1906), Eccles [16] (1906), and Fleming and Coursey [17] (1916) have indicated that the thorough shaking which the magnetic units of the iron receive under high frequency magnetization produces somewhat the same effect on the slowly changing magnetic cycle as is produced by mechanical shocks or vibrations. That is to say, that the oscillations by magnetically jarring the iron allow the impressed field to produce flux changes which would not be produced if the oscillations were absent.

VALUES OF APPARENT PERMEABILITY.

Returning now to the consideration of iron in a single high frequency magnetic field, it may be said that at the beginning of the twentieth century the belief was quite common that magnetic changes of the little molecular magnets of the Weber-Ewing theory were by nature slightly sluggish and that therefore iron was not able to follow rapid magnetic variations as fully as slow ones. This assumption satisfactorily explained the previous experimental observation that the permeability decreased with rising frequency. However, an increasing attention was being paid to the effects of eddy currents and the magnetic skin effect, and investigators recognized more clearly the necessity of considering the form and size of the test piece in interpreting their results.

Several of the papers which follow have been abstracted, not because the data which they contain are of any great present value, but either because they have features of special interest or because the conclusions have helped to shape the trend of scientific opinion in this relation.

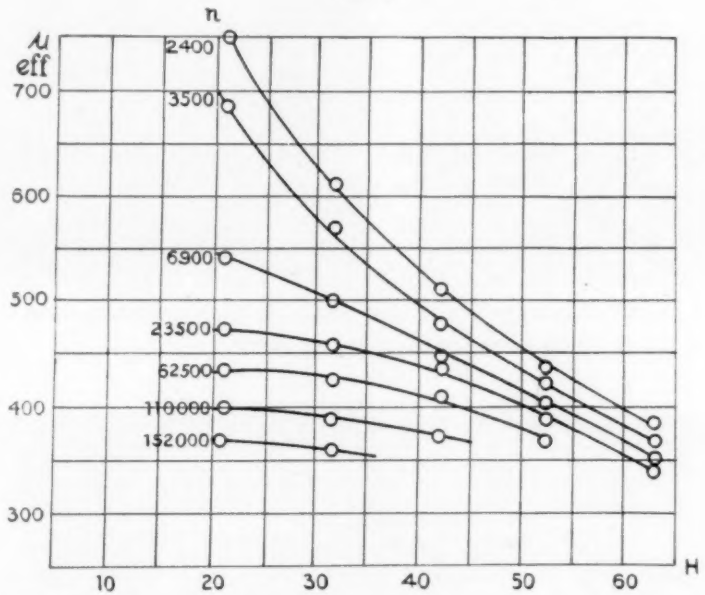
Varley [18] (1902) used a Braun Tube to determine the maximum values of B and H produced by the discharge of leyden jars through a coil surrounding the test piece of fine iron wires. His data are plotted in curves which indicate that within the limit of his observations (up to 130,000 cycles per second) the B-H curve has the same shape at all frequencies, but that much smaller values of B are reached for a given value of H at the higher frequencies.

Braun [19] (1903) made some experiments with iron powder imbedded in paraffine as a core for the coil of an oscillating circuit vibrating at about 5×10^6 cycles per second. Zenneck [20] (1903) following the method of Braun, showed experimentally that iron powder, the particles of which had diameters ranging from 1.5×10^{-3} mm. to 10×10^{-3} mm., imbedded in paraffine might have much higher permeability and much lower core losses at a frequency of 3×10^6 cycles per second than solid iron wires having a diameter of 0.24 mm. It is stated that the magnetic permeability of iron powder in magnetic fields at a frequency of 10^6 cycles per second is nearly the same as in stationary fields. Battelli and Magri [21] (1906, 1908), by measuring the variation in the period of an oscillating circuit when similar iron and copper magnetic circuits were used alternately, and also by measur-

ing the change in the high frequency inductance of coils with and without iron cores, acquired some scattering data.

Undamped alternating currents were used by Schames[22] (1908). The currents were obtained from a Poulsen arc at frequencies up to 220,000 cycles per second. Two similar coils were placed in series with a hot wire ammeter and so arranged that the voltage at their terminals could be measured with an electrometer. One of the coils had an air core and the other a core

FIG. 1.



Apparent permeability of fine iron wires as a function of frequency and field intensity. (Schames.)

composed of a bundle of one hundred soft iron wires 15 cm. long and 0.0051 cm. in diameter each. Measurements of voltage and current in the two coils served as a basis for the calculation of the apparent permeability. The results were shown in the form of curves which exhibit the apparent permeability as decreasing when either the field intensity or the frequency increases. These curves are reproduced here (Fig. 1) because they give some idea of the magnitude of the effects which may be expected when fine iron wire cores are used in high frequency magnetic circuits. In

commenting on Schames' paper *Science Abstracts* says, "As explaining this action an hypothesis is put forward according to which the μ in a rapidly alternating field has not time to arrive at the end value which it would reach with direct or slowly alternating current magnetization. This hypothesis explains also the results obtained by other workers, notably Varley." Zahn [23] (1909) used damped oscillations and from measurements of the high frequency resistance and direct current resistance of steel wires, found a change of the permeability with a change of the current in the wire, which indicated that μ was not independent of H. Later in 1909 Zahn reported work using Schames' method, operating at 2×10^6 cycles per second, on a core composed of thirty iron wires each 0.0494 mm. in diameter. The results when plotted to μ, H coördinates gave a curve very similar in form to the well-known curve for slow magnetization, showing that frequency had but little effect on the relations between μ and H.

Before considering the effect which the accumulated data began to have on the common conviction voiced in Schames' paper that iron was magnetically sluggish, we may profitably turn to some other researches bearing on the matter.

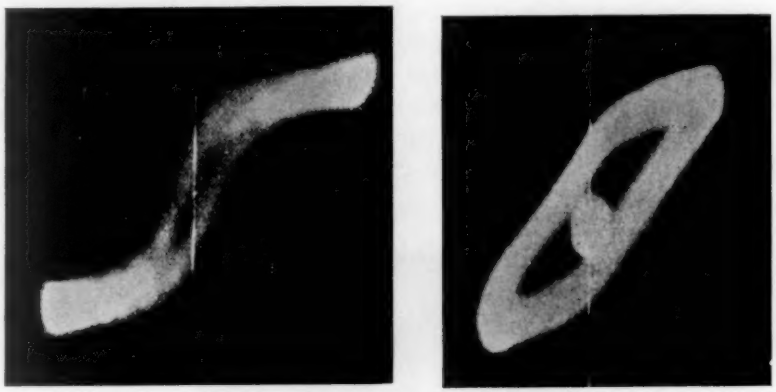
SHAPE OF THE HYSTERESIS LOOP.

At the same time the work just mentioned was going on, a certain set of experimenters was attacking the question of finding the exact nature of the hysteresis loop which the iron follows when acted upon by undamped high frequency fields. The Braun Cathode Ray Oscillograph was ingeniously employed in these researches.

O. M. Corbino [24] (1903) was not only the first to photograph the hysteresis loop of iron at the higher frequencies, but he also was the first to use undamped alternating currents from the Poulsen arc in this kind of work. His test piece and oscillograph were arranged after the method of Ångstrom (*Physical Review*, vol. 10, pp. 74–82, Feb., 1900). The iron core tested was composed of wires 0.25 mm. in diameter. Photographs of hysteresis loops at frequencies from 4 to 20,000 cycles per second were shown in the original publication, the loops at the lower frequencies being slim and showing high saturation, while those at

the higher frequencies were much thickened and distorted by the influence of eddy currents. Two of these loops are reproduced here as Fig. 2 and Fig. 3, respectively. Fig. 2 was made at 4 cycles per second and Fig. 3, which has a much larger area, was

FIGS. 2 AND 3.



Hysteresis loops of iron wires at 4 cycles per second and at 11,000 cycles per second respectively. (Corbino.)

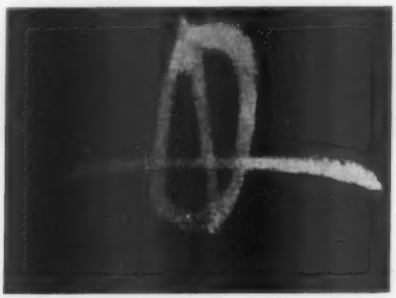
FIGS. 4 AND 5.

Hysteresis loops of fine steel wires at 50 cycles per second and at 10,000 cycles per second respectively. (Battelli and Magri.)

made at 11,000 cycles per second. The work of Schidlof [25] (1905) on the B-H loop, for the purposes of this discussion need merely be mentioned since the highest frequency attained was 1250 cycles per second. Battelli and Magri [26] (1906) also used the Ångstrom method with their Braun Tube but the source of current was a 10,000 cycle alternator built after the designs of

Lamme. (*Trans. A. I. E. E.*, vol. xxiii, p. 417, 1904). One test piece was of steel wires 0.005 cm. in diameter, two were of iron wires 0.01 and 0.03 cm. in diameter, respectively, and one was a solid bar of steel. Photographs of the hysteresis loops shown by these samples at 50 cycles per second and at 10,000 cycles per second form part of the report of these authors. In the case of the steel wires and the 0.01 cm. iron wires the low frequency loop (Fig. 4), and the high frequency loop (Fig. 5) are practically identical except that the former has a slightly larger area. Both are thin and show high saturation. The 50 cycle loops of the 0.03 cm. iron wires and the steel bar are similar to those of the other two test pieces, but at 10,000 cycles the iron wires have a thick

FIG. 6.



Hysteresis loop of solid steel bar at 10,000 cycles per second. (Battelli and Magri.)

stubby loop and the loop of the steel bar (Fig. 6) is an ellipse with major axis nearly coinciding with the B axis. The distortion of the last mentioned loops, which distortion may be seen from Fig. 6 to be large, is ascribed to eddy currents in the test piece. A publication by Corbino [27] in 1907 compared his observation in 1903, that the area of the hysteresis loop increased slightly at higher frequencies, with the observation of Battelli and Magri which indicated the opposite condition, and concluded that the difference must have been due to difference in the test pieces.

THEORETICAL CONSIDERATIONS.

The opinion that experiment had indicated the possibility of explaining the action of iron under high frequency magnetic excitation along purely conventional lines and without ascribing any inherent sluggishness to the elementary magnetic units of the

iron, is registered by the subject matter of certain books issued shortly after 1900.

J. J. Thomson [28] investigated mathematically the transmission of magnetic impulses along a wire. J. Zenneck [29] in a résumé of the work on this subject indicates that a solid iron bar of one centimeter radius acts, for high frequency magnetization, like a tube in the sense that practically all the magnetic field is in a thin surface layer. This phenomenon is called magnetic skin effect. He includes a discussion of theory and experiment in relation to this behavior of metal cylinders.

The attitude of some advanced thinkers at this time (1909) is put very clearly and concisely by Steinmetz,[30] who says: "To fully utilize the magnetic permeability of the iron it therefore has to be laminated so as to give at the impressed frequency practically uniform magnetic induction throughout its section, that is, negligible eddy currents. This, however, is no longer the case even with the thinnest possible laminations at extremely high frequencies as oscillating currents, lighting discharges, etc., and under these conditions the magnetic flux distribution in the iron is not uniform but the magnetic flux density B decreases rapidly and lags in phase with increasing depth below the surface of the lamination, so that ultimately hardly any flux exists in the inside of the laminations, but practically only a surface layer carries magnetic flux. The apparent permeability of the iron decreases at very high frequency and this has led to the opinion that at very high frequencies iron cannot follow a magnetic cycle. There is, however, no evidence of such a 'viscous hysteresis,' but it is probable that iron follows magnetically even at the highest frequencies, traversing practically the same hysteresis cycle irrespective of the frequency of the true M. M. F., that is, if the resultant of the impressed M. M. F. and the M. M. F. of the eddy currents in the iron is considered. Since with increasing frequency at constant impressed M. M. F. the resultant M. M. F. decreases, due to the increase of the demagnetizing eddy currents this simulates the effect of a viscous hysteresis." A table is then worked out showing the "penetration" in various materials at various frequencies. "Penetration" is defined as the thickness of a surface layer of flux which has the same density throughout as the real flux has at the surface and which has the

same total flux as actually exists in the material. The table is here reproduced as Table I. By mathematical derivation it is

TABLE I.

Penetration in Centimeters.

Material	μ	Specific resistance	Frequency, cycles per second				
			25	60	1000	10,000	10^6
Soft iron	1,000	10^5	0.0714	0.046	0.0113	0.0036	0.00036
Cast iron	200	10^4	0.504	0.325	0.080	0.0252	0.0025
Copper	1	6×10^5	0.922	0.595	0.144	0.0461	0.0045
Resistance alloys	1	10^4	7.14	4.60	1.13	0.357	0.036

shown, as had been shown by some previous writers, that the speed of propagation of a magnetic impulse into solid iron "is inversely proportional to the square root of the electric conductivity and of the magnetic permeability, but directly proportional to the square root of the frequency. This gives a curious instance of a speed which increases with frequency." It is further shown by calculation that with reference to an iron plate only 0.036 cm. thick, when the real permeability μ is 1000 and the specific resistance 10^5 microhms per centimeter cube, the apparent permeability $\mu' = \frac{B_{av.}}{H}$ will have values at various frequencies as follows:

Frequency.	Permeability
Very slow	1000
10,000 cycles per second	198
1,000,000 cycles per second	18.8
100×10^6 cycles per second	1.98
392×10^6 cycles per second	1.0

At still higher frequencies it is stated that the presence of the iron will actually reduce the magnetic flux.

In the experimental field again, Drysdale[31] (1911) in some investigations on longitudinal magnetic waves along an iron bar found that the bar acted like an electric cable in which there is no capacity. According to his conclusions the reluctance of the bar corresponds to resistance in a cable and the eddy current coefficient of the bar corresponds to the inductance of a cable.

CORROBORATIVE EXPERIMENTS.

Efforts to determine whether "iron follows magnetically even at the highest frequencies traversing practically the same hysteresis cycle irrespective of the frequency of the true M. M. F." (Steinmetz) were made by Fassbender and Hupka [32] in 1913. Using an arrangement of the Braun Tube and the tuned secondary circuit of a Poulsen arc they obtained on the screen, curves whose coördinates were, respectively, the sinusoidal magneto-motive force in the field of the magnetizing coil around the iron sample, and the voltage at the terminals of the magnetizing coil. The voltage variation was separated by the usual procedure (see H. J. Ryan, *Trans. A. I. E. E.*, vol. 22, p. 545, 1903) and reduced to rectangular coördinates of time and voltage. This wave, integrated by a graphical method (see Bedell & Bown, *Electric Journal*, vol. 12, p. 23, 1915), yielded the flux cycle which, combined in its proper phase relation with the sinusoidal M. M. F. on B-H coördinates, gave the hysteresis loop followed by the sample. Reproductions of voltage and flux waves and of photographs of the original figures were shown in the publication. The three samples of iron laminations 0.03 mm., 0.06 mm., and 0.10 mm. thick, respectively, were submitted by the Telefunken Company. It is stated that the field strength in the iron was 30 gausses. Tests were made at frequencies of 30,700, 56,600, 89,700 and 132,000 cycles per second. Some of the conclusions reached may be freely translated thus: "The photographs and also the curves for a given iron sample show, for the different frequencies little relative variation, although the set of curves for one test piece is quite different from that for another test piece. The thinnest of the test plates (0.03 mm.) shows on the whole the most typical iron curve. In the test of the 0.06 mm. thickness plates the figure shown by the oscillograph, on account of the magnetic skin effect degenerates into an ellipse. The sheet of 0.10 mm. thickness exhibits a gradation between both the other test plates. It is surprising that in the thickest plates the skin effect apparently exercises a smaller influence than in the 0.06 mm. plate." To show that this was not an experimental error the work was repeated with variations of conditions without change in the results. The authors believe that with such thin laminations the rolling process may have a large effect on the amount of active material in the plates. The surface layers of oxide,

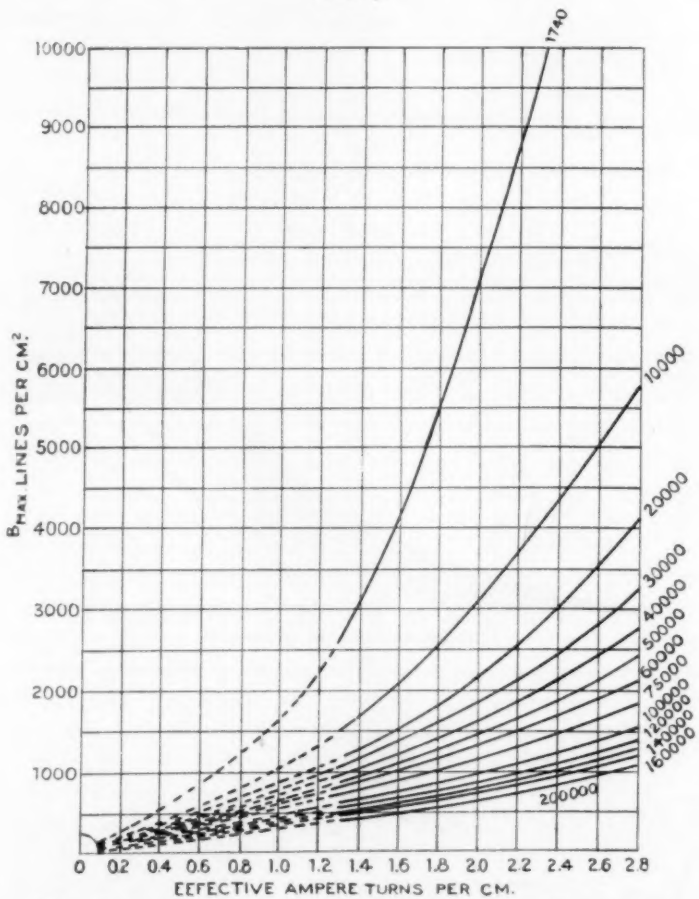
etc., form a considerable part of the total thickness and these surface layers are upon examination shown to be quite variable. The results of the experiments of Fassbender and Hupka even more definitely than those of some previous researches substantiate the view that when magnetic skin effect is greatly reduced by the use of iron laminations having large surface as compared with their cross section, the permeability and the character of the hysteresis loop are but little affected by a wide range of frequency variation. A few later experiments which had some bearing on this conclusion will be briefly mentioned.

Rohmann[33] in 1914 published some interesting photographs of Braun Oscillograph records of magnetic cycles in steel and iron samples magnetized by damped oscillating currents at about 3×10^5 cycles per second. Jonaust[34] (1910) and Bonazzi[35] (1911) worked with undamped and damped oscillations, respectively. Marchant[36] (1913) using leyden jar discharges at 5000 to 100,000 cycles per second through coils with iron cores, photographed the spark discharge in a revolving mirror and obtained results which show the same general characteristics as those of other workers. It is stated that in calculating the results skin effect was taken into account. In the conclusions the author remarks, "The curve connecting μ the 'effective' permeability ($= \frac{Bav.}{H}$) with H the magnetizing force agrees within the limits of experimental error with that obtained on the assumption that the permeability of the iron is the same as it is under a steady magnetizing force."

The matter of the behavior of μ having been fairly well settled, more attention was focused upon the practical question of core losses. By means of his 200,000 cycle alternator Alexanderson,[37] in 1911, was able to get such steady conditions for his measurements as to make simpler the collection of a large amount of accurate data. The sample was an iron ring 5.1 cm. in diameter made up of ten turns of a soft iron strip 0.0076 cm. thick and 1.9 cm. wide. The layers of the strip were separated by thin paper and the winding was made of silk covered copper wire with two wires in parallel and twenty turns in series. "The skin effect measurements consisted in determining the apparent permeability of the iron at various frequencies (40,000 to 200,000 cycles per second), and flux densities by observing the volts and

ampères at the terminals of the sample coil." The core losses were measured by a substitution method. Although the experiments were made largely to determine how the iron could be used in high frequency apparatus, the results were also inter-

FIG. 7.

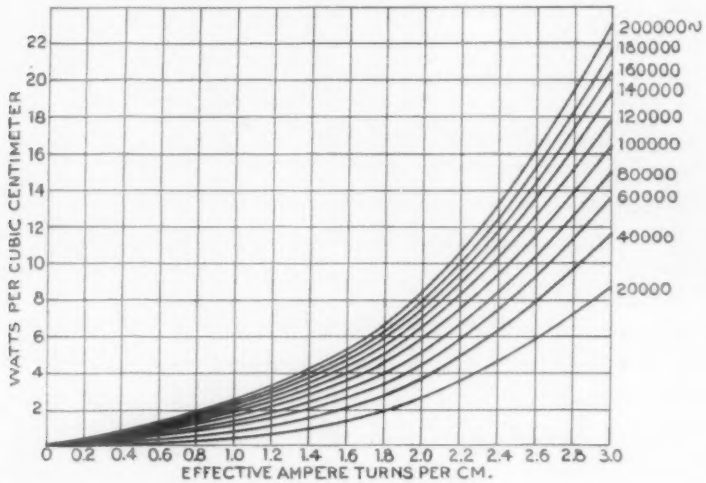


Alternating current saturation curves of very thin sheet iron. (Alexanderson.)

preted in the light of theory. The paper says, "As a conclusion from these tests it may be stated that the opinion held quite extensively that iron does not respond to high frequencies is entirely without foundation. The iron not only responds but seems to have the same permeability at 200,000 cycles per second as at

60 cycles per second. The apparent permeability of the iron in the sample which was tested is only about one-tenth as great at the high as at the low frequencies, but the decrease of the apparent permeability is substantially in agreement with the change that would be expected from purely theoretical considerations due to the skin effect, which indicates that the actual permeability has remained unchanged." Calculation by Steinmetz's formula shows the penetration at 200,000 cycles per second should be 0.00056 cm., while calculation from the data shows it to be 0.0003

FIG. 8.



Core losses in very thin sheet iron as a function of frequency and field intensity. (Alexanderson.)

cm. "The discrepancy between the measured and calculated values of the penetration is probably due to the fact that the coil has not a completely closed magnetic circuit, but depends upon leakage from turn to turn of the laminations, whereby an additional skin effect is created." The iron sheets used by Alexanderson are about as thin as can be manufactured nowadays, and therefore his results are particularly interesting because they show what can be done with iron in high frequency fields when a proper method is pursued. The saturation curves and curves of core losses are copied here as Fig. 7 and Fig. 8, respectively.

In the discussion of Alexanderson's paper, Silsbee [38] reported some experiments made by him in 1910–11. Toroidal rings 8 cm. in diameter and 0.2 sq. m. cross section were made of in-

sulated iron wires from 0.050 mm. to 0.228 mm. in diameter. These were wound with magnetizing coils through which passed 350,000 cycle current from a Poulsen arc. Magnetizing current and voltage were recorded. The calculations included skin effect, hysteresis and eddy currents. The results showed that the real permeability of the iron after these factors had been allowed for was practically the same at 350,000 cycles as at low frequencies, "at least over the range of H used." This range is not stated. "The observed values of the energy component were uniformly low which suggested that possibly the hysteresis loss per cycle might be less at higher frequencies when the molecules are subjected to such rapid agitation."

McLachlan [39] (1915) made core loss tests on 0.33 mm. plates of two special steels known as Stalloy and Lohys, and reported data as in Table II. A strip of the steel placed in the magnetizing

TABLE II.

B max. apparent	H max. apparent	μ apparent	Watts per kilogram	Frequency cy. per sec.
3500	21	170	48,000	1.9×10^5
4300	17	250	44,000	1.7×10^5
3200	25	130	57,000	2.1×10^5

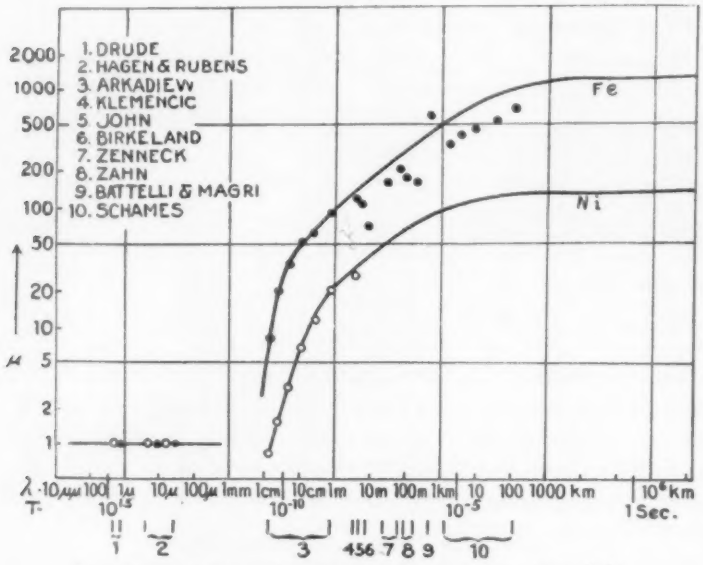
coil became red hot in three seconds unless surrounded by water. These figures show the enormous values to which the core losses may rise under extreme conditions. Tests (1916) of apparent permeability and core losses at frequencies up to 10^6 cycles per second resulted in data consistent with those of previous work.

BEHAVIOR AT EXTREME FREQUENCIES.

While experiment has shown that the true permeability of iron is unaffected by frequency through a range from zero to perhaps 10^6 cycles per second, yet it must be noticed that this cannot be true at much higher frequencies, for at the frequency of light and heat waves the permeability of all metals is unity. What happens in the region between these widely separated conditions was investigated by Arkadief [40] who writes, "In the winter of 1907–08 I busied myself with measurements by different methods of the reflecting power of metallic wires for electric waves and I have found that the difference in the relations between magnetic and non-magnetic wires is much larger for the

longer waves (30 cm.) than for the shorter ones (3 cm.). This, one can only explain by the decrease of the permeability with wave length. In an earlier theoretical and experimental research I have given mathematical formulæ for the calculation of the absorption coefficients for undamped electric waves in two parallel wires and I have found that the measured values for non-magnetic wires are in good agreement with the theoretical values, which makes possible the calculation of the permeability of magnetic wires from the values of their measured absorption coefficient."

FIG. 9.



Compilation of data on high frequency permeability. (Arkadief.)

These earlier investigations [41] of Arkadief consisted in measurement by means of a delicate thermo-element of the attenuation or absorption of electric waves propagated along two wires. The energy of the waves is found to fall off according to an exponantial relation. Calculations based on a theoretical formula showed that for non-magnetic materials the observed and calculated values of the absorption coefficient differed by less than the possible experimental error, which was small. Data from observations on similar magnetic wires were then placed in the

formulæ and, working backward, the value of μ was deduced. For soft Swedish iron wires 0.02 mm. in diameter in very weak fields the values were:

Wave length in cm.	Permeability, μ
72.7	80.
23.8	58.
10.63	51.
4.82	33.5
2.31	14.7
1.31	4.5

The extrapolation of these data showed that μ became unity for iron with waves a few millimeters in length. A curve is drawn [40] (reproduced here as Fig. 9) which exhibits Arkadief's results as connecting smoothly the results of Rubens in the region of heat waves with those of other experimenters at wave lengths near 1000 meters. Further experiments by Arkadief [42] in which the energy of short waves reflected from a lattice of fine wires of magnetic material was measured by a delicate thermo-element, confirmed the accuracy of the previous investigations of that author.

The question of what happens to μ, or in fact of what meaning the ratio B/H has in the region of wave length which lies about the natural radiation wave lengths of atoms and molecules, is a question which is too undecided to even conjecture upon here. The matter obviously involves theories of the magnetic structure of materials which are far from settled. Arkadief [43] has made some mathematical investigations of what is to be expected in this region.

SUMMARY.

Not many years ago it was quite generally believed that iron was unable to follow rapid magnetic changes. Experiments which showed an apparent decrease in the permeability of the iron with an increase in the frequency of the magnetic cycle furnished a basis for a theory that iron was magnetically sluggish. Further and more accurate experiments proved, however, that the effects which had previously been ascribed to a peculiarity of the material were in reality caused by eddy currents in the sample. Theoretical calculations were made which demonstrated that eddy currents in an iron test piece increased as the square of the fre-

quency and that for even the lower frequencies it was necessary to use quite thin laminations in magnetic circuits in order to eliminate deleterious effects. Furthermore, it was found that due to eddy currents and the magnetic properties of iron, the magnetization in high frequency fields was confined to a thin surface layer of the piece. This "Magnetic Skin Effect" reduced the cross section of the iron which was magnetically active even though the laminations were extremely thin. Careful experimental measurements compared with theoretical calculations proved that the real permeability of iron remained unchanged at frequencies up to about 10^6 and that previous results had been in serious error due to neglect of the factors mentioned. This fact having been established, efforts were made to see what practical use could be made of iron in high frequency work and to that end some extensive experimental investigations of the saturation curves and core losses were made upon specimens laminated as thinly as was commercially practicable. The resulting data have furnished a basis for design.

It is a demonstrated fact that the permeability of all metals is unity for the magnetic cycles imposed upon them by heat and light waves. In the region between frequencies of about 10^6, where the true permeability of iron is practically the same as at zero frequency, and frequencies of about 10^{10} where the true permeability of iron approaches unity, the experimental values of μ decrease smoothly with the frequency. What happens to μ in the range of frequencies between the longest heat waves and the shortest Hertzian waves which have yet been made is a question which has many interesting features but which has not yet yielded to the experimenter.

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Nickel and Tin. C. S. TRENCH. (*Brass World*, vol. 12, No. 11, November, 1916.)—Nickel and tin are the only metals we seem unable to find among our mineral resources. There is no substitute for tin. Unlike other metals, the price has no effect on consumption. If tin were at 15 cents we would perhaps put more on our tin plates and make better solder and babbitt metal. If it were one dollar per pound we would still have to use it for nearly every use for which it is employed. Tin is one of the weakest points in America's self-sufficiency as a nation. The effect of being cut off from tin would create sanitary troubles that would prove very serious. In the opinion of the writer, tin at present prices is on a safe basis and after the war much higher prices are to be expected. Tin is the only metal selling to-day at less than the average price of two years before the war, the price being 10 per cent. lower, while the prices of other metals are 52 to 180 per cent. higher.

Research Fellowships in the Engineering Experiment Station of the University of Illinois.—The value and the need of organized industrial research, carried on upon a scale in keeping with our very large natural resources, are becoming more and more appreciated and recognized. Private laboratories of industrial research have already demonstrated their utility in yielding handsome returns to their promoters and notable contributions to the advancement of science. Only too few laboratories of that type are maintained by educational establishments, and, at this hour of a general awakening to the importance of the movement, the announcement that nine vacancies among the Research Fellowships in the Engineering Experiment Station of the University of Illinois will be available at the close of the current academic year is of most timely interest.

The Engineering Experiment Station, an organization within the College of Engineering, was established in 1903 for the purpose of carrying on investigations in the various branches of engineering, and for the study of problems of importance to engineers and to the manufacturing and industrial interests of the State. The work of the station is closely related to that of the College of Engineering, and the heads of departments in the college constitute the administrative station staff. Investigations are carried on by members of the station staff and other members of the instructional staff of the College of Engineering by special investigators employed by the station, and by the research fellows. Nominations to these fellowships, accompanied by assignments to special departments of the Engineering Experiment Station, are made from applications received by the Director of the Station each year not later than the first day of February.

Additional information may be obtained by addressing the Director, Engineering Experiment Station, University of Illinois, Urbana, Illinois.

THE LUMINOUS EFFICIENCY OF THE RADIATION FROM THE ELECTRIC ARC.

BY

ENOCH KARRER, Ph.D.,

Member of the Institute.

In a previous work [1] a method for obtaining the luminous efficiency of the radiation of a light source was perfected and values for the luminous efficiency of the radiation from various common light sources both gas and electric were given.

It was found that the method employed in the investigation of ordinary light sources was quite unsatisfactory for investigating the arcs, for the variations that are continually present in the arc would necessitate the taking of a very large number of observations.

There are obviously several methods which may be used to avoid this difficulty. One of the first to suggest itself was to have some means of recording the ratio of the two quantities required (viz., the total radiation and the radiation through the "luminosity" screen). This might be accomplished with a bolometer arrangement in which the material as a platinum strip of one arm of a Wheatstone's bridge is exposed to the whole radiation, while that in the other is exposed to the same radiation after passing through the luminosity screen. This method had already been suggested by Ives.[2]

A second method would be to record a large number of observations photographically, and take a mean directly from the curve such as a photographic recording device would give.

A third method would be to have some integrating means whereby the average rate of energy-radiation over an extended time could be obtained.

The photo-electric cell perhaps could be adapted to this end for measuring the radiation through the luminosity screen, or possibly some photo-chemical means. For an integrating total radiation meter, however, no simple means is at hand.

[1] *Physical Review*, n. s. vol. v, No. 3, p. 189, March, 1915.

[2] *Electrical World*, June 18, 1912.

A Nichol's or a Crooke's radiometer might possibly be made to operate some mechanical or electrical device to this end. Or the radiomicrometer might perhaps be developed into an integrating radiometer.

There is a fourth method, however, which is simple and direct. Its disadvantage is that it necessitates duplication of apparatus.

If two thermopiles are at hand, two sensitive galvanometers, and two observers, it is obviously simple to record approximately simultaneous conditions of the light source as to its radiation with and without the luminosity screen.

This method is the one employed in the present investigation. Two galvanometers were employed, though one galvanometer may be dispensed with as will be noticed later. The one galvanometer will be referred to as Galvanometer I, and the other as Galvanometer II. Galvanometer I was a high sensitivity Leeds and Northrup's galvanometer, whose description as given by the makers is as follows: sensibility 33 mm. for 1 microvolt across the terminals; resistance 12.5 ohms, critically damping resistance 32 ohms, period 7.5 seconds. Galvanometer II was constructed by the author some time previously, and modified to suit the present purpose. Its sensibility was obtained by comparing with Galvanometer I. When the two galvanometers were connected in series with a resistance, and an ordinary dry cell, so that the same current was flowing through the galvanometers, Galvanometer II gave deflections 2.6 times as large as Galvanometer I. When the same potential difference was put across the terminals of each galvanometer, separately, Galvanometer II gave deflections 3.6 times as large as Galvanometer I.

For this latter comparison a dry cell with a suitable resistance in series was connected to the terminals of each galvanometer in succession.

The resistance of Galvanometer II was approximately 26 ohms; period 7 seconds. This comparison does not give an adequate estimate of the relative merits of the galvanometers perhaps, for it will be shown below that each galvanometer had its own superior qualities.

The two thermopiles will be denoted as Thermopile I and Thermopile II.

Thermopile I was taken from the infra-red spectrometer manu-

factured by the Adam Hilger Co., London. It consists of ten Bi-Ag junctions in series, and had a total resistance of about 3 ohms. Its receiving surface was 2 mm. × 10 mm.

Thermopile II was constructed by Dr. W. W. Coblentz. It consisted of twenty junctions in series of bismuth and silver with a total resistance of about 12 ohms. Its receiving surface was 3 × 22 mm. approximately.

With the thermopile and galvanometers having such different resistances there was of course some choice as to the combinations of thermocouple and galvanometer to be used, and those giving greatest sensibility for the work at hand could be selected.

To show the difference in the behavior of the galvanometers when connected with first, Thermopile I, and secondly with Thermopile II, the following table is given:

	Relative sensibility	Time to reach maxim. deflections
Galv. I with Thermopile I.....	2.8	13.5 sec.
Galv. I with Thermopile II.....	3.5	8.0 sec.
Galv. II with Thermopile I.....	1.8	23.0 sec.
Galv. II with Thermopile II.....	4.1	20.0 sec.

These deflections were obtained when the radiation from a tungsten filament lamp (40 watts) operated at 112 volts was allowed to fall upon the thermopiles. The lamp was 23 cm. away; the scale about 1 meter distant.

It is seen here that Galvanometer I gives greater deflections with Thermopile II than with Thermopile I, and Galvanometer II gives also the greater deflections with Thermopile II. For brevity we shall designate the latter combination as Radiometer II: and the Galvanometer I together with the Thermocouple I as Radiometer I. These differences in sensibility are such as may be expected from a consideration of the resistances of the galvanometer and of the thermopiles, yet it shows the importance of choosing the proper galvanometer for a given thermopile and the proper thermopile for a given galvanometer.

Radiometer II was 40.6 per cent. more sensitive than Radiometer I. The Radiometer II was the most sensitive combination of thermocouple and galvanometer available, and was employed throughout the test to measure the radiation after passing through the luminosity screen; while Radiometer I was employed to measure the radiation directly.

The deflections actually obtained with the former for ordinary illuminants when the luminosity screen was interposed were, of course, very much smaller than those obtained with the latter exposed to the full radiation. To make the deflections comparable the slit in front of the Thermocouple I was closed, so that a very small part of its total receiving surface was exposed.

The two radiometers as used were tested for linearity of deflections by exposing to the radiation from a tungsten lamp which was placed at various distances. It was found that up to quite large values, 20 to 30 cm., the deflections were proportional to the intensity of the radiation to within one per cent.

The Radiometer I was calibrated in terms of Radiometer II, for it is to be noted that the Radiometer I was employed merely to indicate what the Radiometer II would have indicated when the luminosity screen was not before it. To reduce deflections given by Radiometer I to those given by Radiometer II they are to be multiplied by 34.4. Corrections for optical path and for the absorption by the cell were made later and are not included in the factor 34.4.

The luminosity screen used was the combination specified by Ives [3] and described in detail by Ives and Kingsbury [4] in connection with a method of physical photometry. It consists of a 1 cm. thick tank containing a mixture of copper chloride, potassium chromate and cobalt ammonia sulphate, together with a protective tank of water 2.5 cm. thick. This combination has been exhaustively tested by them as to its agreement with the visual luminosity curve, and also as to the adequacy of the water layer to block all infra-red radiation transmitted by the colored elements in the 1 cm. tank.[5] The cell allowed 57 per cent. of energy to pass at the wave length of its maximum transparency.

The thermopiles, placed side by side, were enclosed in a large tin box packed with cotton and carefully shielded from all extraneous radiation by many screens of heavy cardboard stationed at short intervals between the light source and the radiometers. The screen next to the source was a photometric screen made

[3] Trans. Ill. Eng. Soc., x, 4, p. 315, June, 1915.

[4] *Physical Review*, Nov., 1915, p. 319.

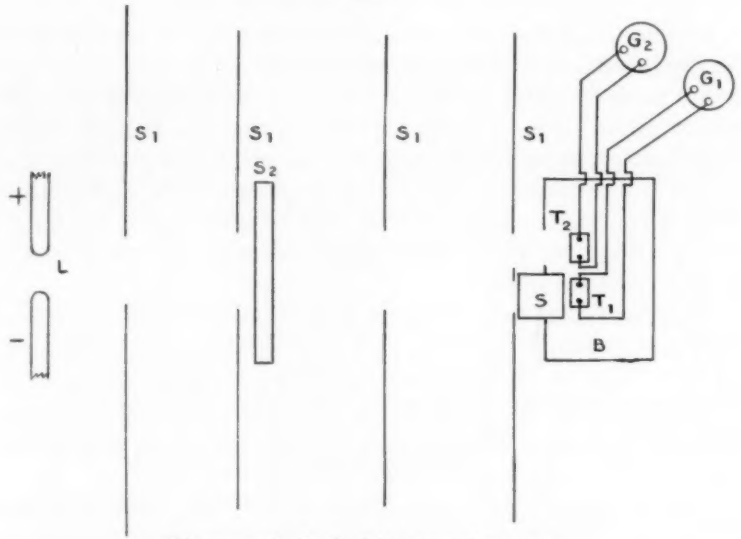
[5] "The Luminous Efficiency of the Carbon Incandescent Lamp and the Mechanical Equivalent of Light," *Physical Review*, vol. 8, p. 254, 1916.

of sheet iron and about 16 inches by 24 inches and one-sixteenth of an inch thick. The shutter consisted of a wooden frame covered on one side with bright sheet iron (commonly called "tin") and on the other with blackened cardboard. The air space was approximately three-eighths of an inch. This double screen had been found very satisfactory in the earlier work.

Fig. 1 is a schema of the disposition of the apparatus.

(L) is the light source studied; (S_1) screens; (S_2) double walled shutter; (B) sheet iron box enclosing thermocouples (T_1) and (T_2); (S) cell containing the luminosity solution.

FIG. 1



Diagrammatic sketch of the set-up of apparatus.

The thermocouple (T_1), together with the galvanometer (G_1), constituted Radiometer I and the Thermocouple (T_2) with galvanometer (G_2) constituted Radiometer II.

The thermocouples were both mounted in heavy brass enclosures as usually done by makers of these instruments.

Long portions of the leads from the thermocouples to the galvanometers were retained within the walls of the enclosure B which was loosely filled with cotton.

The electrodes of all the arcs investigated were held vertical in a pair of carbon holders made for the "Excello" arc lamp. Two

vertical iron rods were adapted as slides for the holders so that the electrodes could be set at any desired distance apart. The lower electrode holder was held in a clamp. All electrodes were held in these holders and when necessary the diameters of the ends were turned down in the lathe until the holders could receive them. The apertures in the screens were such that a portion of the electrodes to either side of the arc could radiate on to the thermopiles. The holders, however, were not always in a position to do so. The arc was made by lowering the upper electrode until it made contact with the lower.

All measurements were made in a horizontal direction, and at a distance of from 1 to 1.25 meters from the arc.

Emphasis must be laid upon the fact that the values here given refer to a particular direction and to the arc in most cases with little or no accessories. Any variations in the latter will of course give different values by varying the relative amounts of energy dissipated by the source through the channels of convection, conduction and radiation. This was pointed out in the earlier paper referred to above. This must be kept in mind when the figures given here are compared with other constants and properties of the light sources studied.

The electrodes were obtained at the time the work referred to above was in progress (in the spring of 1914). These electrodes had been kept in their original packing in the basement of the laboratory where the temperature and moisture conditions were somewhat variable. On several of the carbons were noticed light grayish specks which could be quite easily brushed off.

The results obtained are in most part shown in the diagrams of Fig. 2. These are not to be taken as curves depicting the behavior of the various arcs. The points plotted in most cases represent isolated, widely separated observations, but connected by straight lines to avoid confusion. One may get a rough comparison of the various arcs as to the efficiency of their respective radiation by a glance at the points indicated in the figure.

Eleven arcs in all were studied. The data for the Arcs I and II have been omitted. A different absorption cell was employed, whose maximum transmission had not been determined.

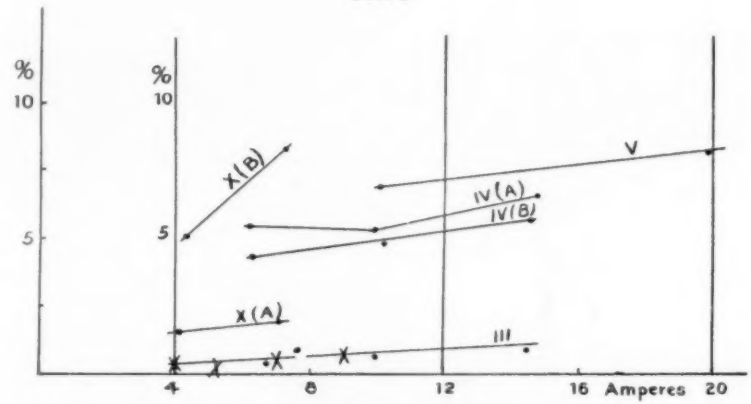
Electrodes in Arcs I and II were solid carbon and the small luminous arc carbons. Data for both of these types were again obtained with the luminosity solution finally employed, and are

given under Arcs III and IV. Only in one case were determinations made on the arc with its complete fixtures as it is obtained on the market. This was the so-called "Excello" lamp. The electrodes used in this instance were the yellow flame carbon 8 and 9 mm. × 600 mm. It was operated under normal conditions, *i.e.*, on 10 ampères and 55 volts.

A cooling curve was taken for this lamp so that correction could be made for the radiation from the inner and outer globes, and such portion of the metal fixtures as may have been contributing.

In all cases at least two different sets of electrodes for every

FIG. 2



Curves showing the relationship between luminous efficiency of the radiation from and the current through the arc.

condition were used. From three to six observations were made for every condition for every pair of electrodes.

The values given in the table below and plotted in the curves of Figs. 2, 3 and 4 are the mean values of these observations. A detailed description is given below of the electrodes used and of the conditions under which they are normally used. Roman numerals refer to the same arc as the curves marked with the same numerals in the Figs. 2, 3, and 4.

III Ordinary D. C. 110 volts solid carbon ½ inch × 12 inches vertical trim, 80 volts at arc; 5 ampères for use in enclosed arc lamp. This type of carbon is being superseded by the flame arc carbons.

IV. Luminous arc, Columbia, silver tip, yellow flame, cored

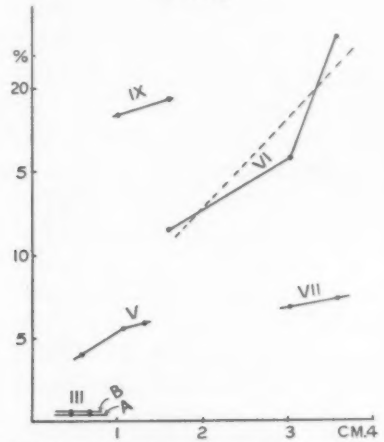
carbons, negative electrode 9 inches × 600 mm., positive electrode 10 mm. × 600 mm.

V A. C. Luminous arc, yellow flame carbons cored, 8 × 600 mm. Carbons IV and V are designed for the incline trimmed lamp two in series on 110 volts; 45 volts at arc. These carbons have the flame material in the core and are for use in a semi-enclosed lamp, such as the " Excello."

VI A. C. 7/8 inch × 14 inches; 441 H. Yellow flame Homogeneous.

VII A. C. 7/8 inch × 14 inches; 452 H. White flame Homogeneous.

FIG. 3



Curves showing the relationship between the luminous efficiency of the radiation from the arc and the length of the arc.

VIII D. C. 7/8 inch × 14 inches; 452 H. White flame Homogeneous.

IX D. C. 7/8 inch × 14 inches; 441 H. Yellow flame Homogeneous.

Carbons in Arcs VI, VII, VIII and IX have the flame material directly embodied in the body of the carbon. They are designed for operation in vertical trim enclosed flame arc lamps such as the G. E. Co. form W. lamp.

The No. 441 H. yellow flame carbons are adapted for D. C. service at 7 ampères, 65 volts at arc on 110 volt line. Tests were also made with A. C. at 10 ampères, and 65 volts on the suggestion of Mr. R. B. Chillas.

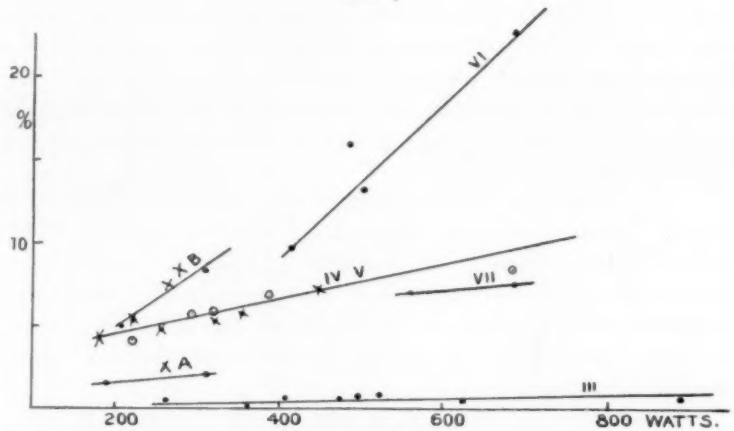
The No. 452 H. White flame Carbons are for A. C. service at 10 ampères or D. C. at 7 ampères and 65 volts.

The solid flame carbons are for enclosed arc service. When burned with full access of air an insulating slag forms, which at times gave a little trouble during the work, and had to be removed.

X Standard magnetite carbons are used on D. C; 4 to 7 ampères with the electrode as cathode: the anode may be a block of copper.

XI " Excello " lamp equipped with luminous carbons described under IV.

FIG. 4



Curves showing the relationship between the luminous efficiency of the radiation from and the rate of energy consumption by the arc.

The lamp was operated on 110 volts D. C. with a suitable resistance in series with it as is supplied with the lamp.

XII Magnesium flame three-ply wire about 0.5 mm. diameter.

A magnesium wire was at hand. This was twisted three-ply, lighted with a match and held before the radiometers. Several observations were made. It was difficult to keep the flame at the proper place, and large variations are to be found in the observations. The value given is a mean value.

The results for all the arcs are not indicated in the Figs. 2, 3, and 4. In some instances points at sufficiently great distances apart had not been obtained. Such data are only given in the table.

In Fig. 2 are indicated the points for Arcs III, IV, and V and X plotted against current.

In III the dots represent points for the Arc III when the electrodes were .68 cm. apart; while the crosses are points obtained when the electrodes were .47 cm. apart. Both sets of points fall upon the same straight line.

For the Arc IV the points on IV (A) are for a distance between the electrodes of 1.08 cm., while IV (B) are points for a length of arc 0.59 cm. The two sets of points fall to within the limits of accuracy on lines which are parallel.

For curve V (Arc V) the electrode distance was 1.33 cm. For the magnetite Arc X, curves X (A) and X (B) are both for an arc length of 0.55 cm.; in the former, however, a small brass rod ½ inch in diameter was used as anode. That such a difference in the character of the radiation may be expected is obvious; that it is as great as these few determinations of the luminous efficiency indicated cannot be averred.

It is to be noticed that a change from 0.68 to 0.47 cm. in the length of the common solid carbon arc (Arc III) does not change the luminous efficiency of its radiation. While in the case of the yellow flame Arc V an increase in the length of arc brings about an increase in the luminous efficiency of its radiation. This is also shown in Fig. 3 where the luminous efficiency is plotted against the length of arc.

For the common solid carbon Arc III, curves III A and III B Fig. 3, III A is for a current of 6.7 ampères through the arc, while III B is for 9.5 ampères. All the points lie on lines parallel to the abscissæ.

In curves V Fig. 3 it is shown that the luminous efficiency of the radiation of the yellow flame Arc V increases with the arc length. The current here was constant at 10 ampères, while the voltage varied from 22.1 to 32.0.

For VI the current was 10 ampères, while the voltage varied from 47.5 to 68.5.

In VII the current was 10 ampères, voltage 56. to 68.2.

In IX the current was 7.39 ampères, voltage 42. to 45.2.

In Fig. 4 is shown the relationship between the luminous efficiency of the radiation and the watts consumed by the arc. For all cases represented the luminous efficiency increased with the wattage.

Points for Arcs IV and V lie on the same straight line. The crosses refer to Arc IV, the circles to Arc V. Arcs IV and V are respectively the D. C. and A. C. yellow flame arcs with 8 and 9 mm. × 600 mm. electrodes.

Curves VI and VII are for the yellow and white flame arcs respectively with electrodes 7/8 inches in diameter. The great difference between these two curves and that between the slopes is perhaps exaggerated here on account of the small number of observations on only a few specimens that possibly had deteriorated slightly with age.

Curve XA, Fig. 4, refers to the magnetite arc when a small anode was used; XB to the same when a large anode was used.

It is to be noted that the A. C. yellow flame Arc VI with large electrodes 7/8 inch in diameter is more efficient than the A. C. yellow flame Arc V with small electrodes 8 and 9 mm. × 600 mm., under the conditions of the experiment, as shown by curves VI and V respectively in Fig. 4.

No. of Arc	Arc length	Amp.	Volts	Efficiency
III	0.68 cm.	6.73	69.8	.0040
	0.68 cm.	9.95	62.76	.0056
	0.68 cm.	14.41	61.51	.0097
	0.47 cm.	4.02	65.76	.0034
	0.47 cm.	6.99	57.92	.0044
	0.47 cm.	9.05	54.87	.0068
IV	1.08 cm.	6.19	35.79	.054
	1.08 cm.	9.94	32.45	.053
	1.08 cm.	14.27	30.60	.071
	0.59 cm.	6.24	29.25	.043
	0.59 cm.	10.18	25.07	.049
	0.59 cm.	14.55	24.56	.057
V	1.33 cm.	10.00	36.6	.069
	1.33 cm.	19.93	34.2	.083
	1.31 cm.	10.00	32.0	.058
	1.08 cm.	10.00	29.3	.057
	0.59 cm.	10.00	22.1	.041
VI	3.01 cm.	10.00	49.2	.158
	3.57 cm.	10.00	68.5	.225
	1.60 cm.	10.00	47.5	.115
VII	3.57 cm.	10.00	68.2	.074
	3.01 cm.	10.00	56.0	.068
VIII	1.6 cm.	7.02	46.6	.095
	1.0 cm.	7.43	35.9	.130
IX	1.0 cm.	7.40	42.0	.184
	0.6 cm.	7.38	45.2	.193

No. of Arc	Arc length	Amp.	Volts	Efficiency
X		small anode		
	0.55 cm.	7.14	43.7	.02
	0.55 cm.	4.09	46.5	.015
		large anode		
	0.55 cm.	7.29	42.7	.074
	0.55 cm.	4.35	47.4	.051
XI	without globes	8.73	59.9	.086
	with globes	8.79	50.2	.114
	Corrected for radiation from globes			
		8.79	50.2	.43
XII	Magnesium Flame			.077

This work was done during the fore part of August, 1915. The publication of it was deferred with hopes that an opportunity might arise when certain portions of the work could be repeated. Since this has not come to pass and there have been several inquiries regarding these values for the arc lamp, I deem it worth while to publish these data now. I believe that the values here given are more definite than any that may be found in the literature.

I am greatly indebted to Dr. W. R. Whitney, of the General Electric Co., for the standard magnetite electrodes; to Mr. R. B. Chillas, of the National Carbon Company, for the ordinary carbon and flaming arc electrodes used; to Mr. C. W. Jordan I am indebted for much assistance given in securing these data; to Dr. H. E. Ives for valuable suggestions and criticism.

The United Gas Improvement Company,
Physical Laboratory,
Feb. 24th, 1916.

A SHUTTER TESTING MACHINE.*

BY

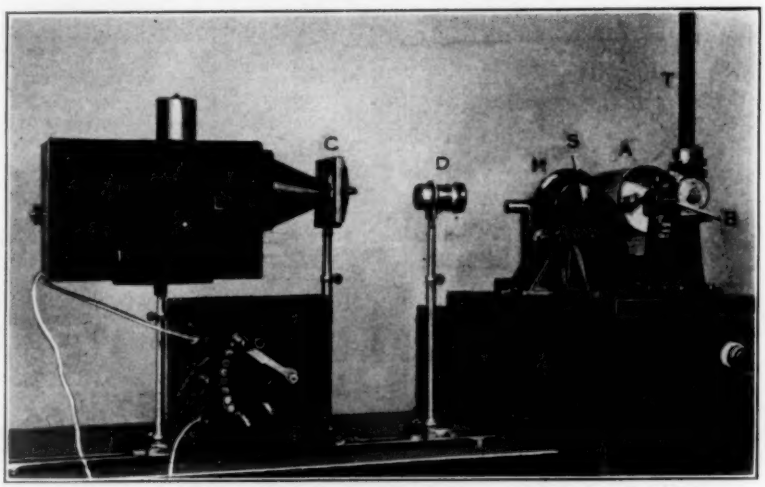
ALFRED B. HITCHINS, Ph.D., F.R.P.S.,
Director, Ansco Company's Research Laboratory;
Member of the Institute.

AND

F. B. GILBERT.

THE want of an instrument of precision for testing the speed and efficiency of shutters has long been felt. To date the machines of Abney and the National Physical Laboratories have been the finest, but they have failed in one or more of the requirements of precision, simplicity of operation, or durability of construction.

FIG. 1.



In the design of the one to be described these three qualities have been kept in view, and it is felt that the work has brought forth an instrument of both laboratory precision and commercial utility.

Fig. 1 shows a complete view. *A* is a revolving drum mounted on a shaft between a powerful high-speed motor *M* and a Veeder precision tachometer *T*. The speed of the drum may be varied by altering the position of the brushes but its fine regulation is achieved by the brake *B*, acting on the shaft. The accuracy of the tachometer is 1 per cent. which with the speed generally used

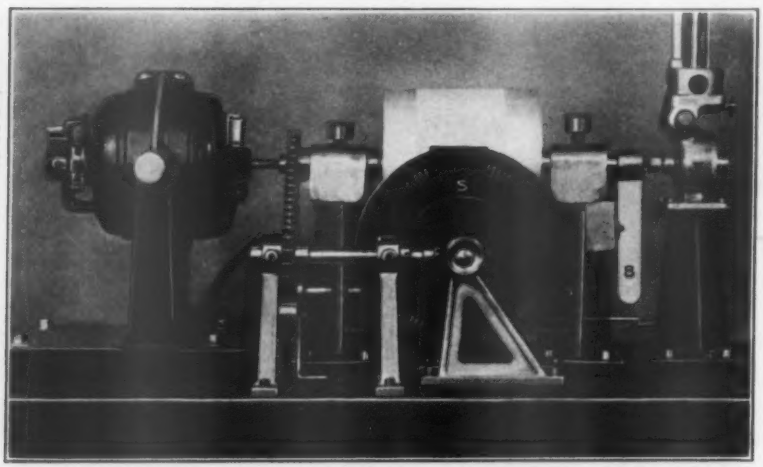
* Communication from Ansco Company's Research Laboratory.

(1250 r.p.m.) only produces an error of 1/5000 of a second in the measurement of a shutter speed of 1/50 of a second.

The shutter to be tested is held in a universal iris *C* directly in front of a narrow horizontal slit. By means of an arc and a pair of condensers in the lamp house *L* this slit is illuminated by a very powerful spot of light, while its image is brought to focus on the drum by the lens *D*. Thus on exposure there is produced on a strip of film affixed to the revolving drum a band, the length of which at a given r.p.m. determines the speed of the shutter.

To make this band self-recording and avoid the tedium of many measurements it is split up into a series of lines by the

FIG. 2.



sector wheel *S* (Figs. 1 and 2) which revolves in front of the drum. The wheel contains 96 slots and by gearing to the main shaft is made to rotate at precisely the same speed as the drum: the series of lines in the image, being due to the interruptions of the sector wheel, have a definite time value. At 1250 r.p.m. each one of the lines then represents 1/2000 of a second, so that, in order to estimate the speed of the shutter, it is only necessary to count these. These may be separated into blocks of ten by obliterating every tenth slot on the sector wheel, reducing the labor of counting. The images produced are shown in Fig. 3 for several different shutters.

Since the drum cannot be revolved at less than 400 r.p.m. with any accuracy or benefit to the motor due to the high braking necessary, shutter exposures of more than 1/50 of a second cannot be measured without overlapping of the image in one or

FIG. 3.

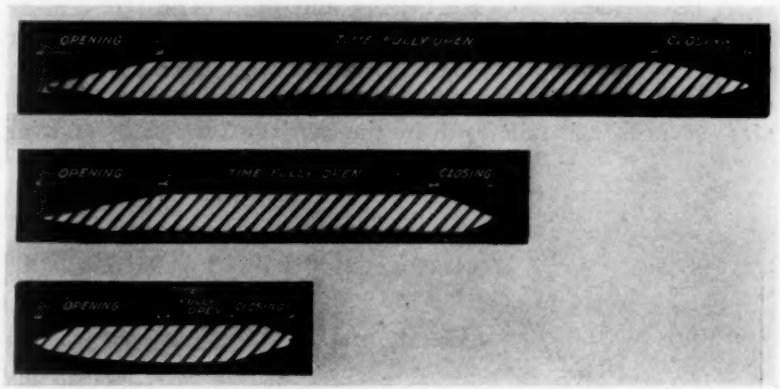
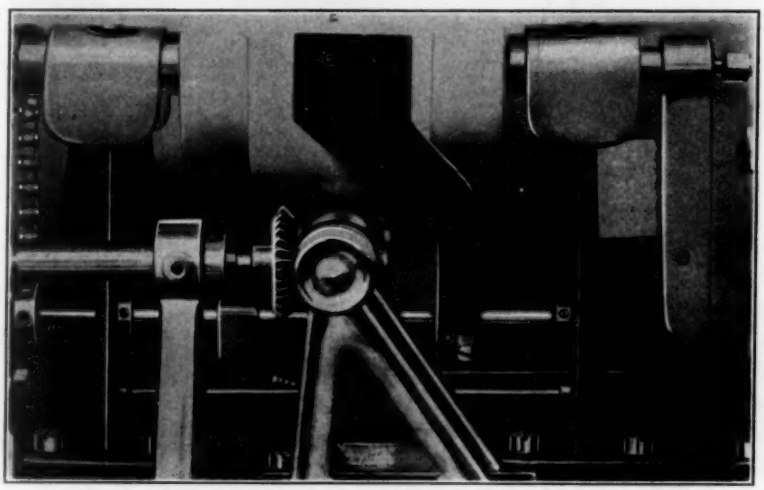


FIG. 4.



more complete revolutions during the firing. To overcome this difficulty a "threader" *E* is used. (Fig. 4.) It is merely a flat piece of metal with a fine slit in it at right angles to the illuminated slit which can be swung into position between the drum and

the sector wheel; its function being to permit only a small dot of light from the slit image to reach the drum. By means of a worm and a threaded finger the slit moves across the drum at the rate of 1/20 of an inch per revolution, thus threading a narrow dotted line around and around the drum as a bobbin winds a spool. The carriage carrying the threader is mounted on a shaft below the drum (see Figs. 5 and 5*a*). The screw is revolved at the same speed as the drum and motion translated to the carriage by the threaded finger *F*. The engagement and disengagement of this finger is controlled by the lever *G*, which also serves as a handle to draw the carriage back to its starting

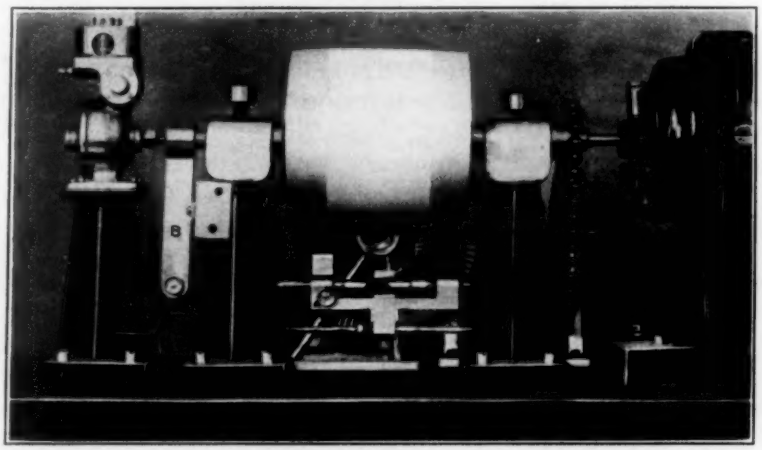
FIG. 5.

position at the left where it will remain until the finger is engaged by depressing the lever, when it travels to the right at the rate given. When this attachment is being used the drum is run at 625 r.p.m. and the speed of the exposure is then measured by the number of complete revolutions, *i.e.*, winding of the thread line plus the number of dots over the last complete revolution. The dots at 625 r.p.m. equal 1/1000 second each.

The actual technique of operation of the instrument for high speeds consists first of wrapping a piece of film tightly around the drum (in which position it can be affixed by merely moistening the ends and sticking them together), the shutter is set to the

speed to be tested, the drum is started and the arc struck. The speed of the drum is regulated by means of the brake *B*, until the tachometer reads 1250 r.p.m. Then the shutter is fired. In measuring the slow speeds the same procedure is followed except that the drum is revolved at 625 r.p.m. and at the moment

FIG. 5a.



before firing the shutter, the lever *G* is depressed, thus starting the threader *E* on its trip across the drum.

Fig. 6 shows the type of image produced by this threader.

Referring to Fig. 3, it will be seen the time of opening and the time of closing of the shutter is represented by the tapering

FIG. 6.

ends of the image. The length of this taper varies with different makes and types of shutters and the diaphragm opening used. It is the factor in determining the efficiency of the shutter. However, it is of interest to note that for the same shutter and diaphragm the length of the opening and closing periods is unvaried

by a change of the speed setting of the shutter. The following table gives the result on some shutters tested.

TABLE

Shutter	Marked speed	Actual Speed	Time fully open	Time of opening	Time of closing
No. 1	1/150 = .0066	.0235	.0165	.0045	.0025
	1/100 = .01	.0220	.0150	.0045	.0025
	1/50 = .02	.0235	.0160	.0050	.0025
	1/25 = .04	.2490	.....	.....	.....
	1/5 = .2	.2980	.....	.....	.....
	1/2 = .5	.3290	.....	.....	.....
	1 = 1.0	.2640	.....	.....	.....
No. 2	1/300 = .0033	.0150	.0080	.0035	.0035
	1/200 = .005	.0230	.0155	.0035	.0040
	1/100 = .01	.0255	.0180	.0035	.0040
	1/50 = .02	.0295	.0130	.0030	.0035
	1/25 = .04	.0360	.....	.....	.....
	1/5 = .20	.1940	.....	.....	.....
	1/2 = .5	.5570	.....	.....	.....
	1 = 1.0	.7140	.....	.....	.....
No. 3	1/100 = .01	.0190	.0113	.0038	.0039
	1/50 = .02	.0220	.0151	.0034	.0035
	1/25 = .04	.0810	.....	.....	.....
	1/5 = .2	.1460	.....	.....	.....
	1/2 = .5	.3590	.....	.....	.....
	1 = 1.0	.5040	.....	.....	.....
No. 4	1/150 = .0066	.0155	.0060	.0035	.0060
	1/100 = .01	.0165	.0040	.0030	.0095
	1/50 = .02	.0220	.0095	.0030	.0095
	1/25 = .04	.0810	.....	.....	.....
	1/5 = .2	.1000	.....	.....	.....
	1/2 = .5	.2110	.....	.....	.....
	1 = 1.0	.4960	.....	.....	.....
	2 = 2.0	1.0300	.....	.....	.....
No. 5	1/250 = .004	.0056	.0017	.0021	.0018
	1/100 = .01	.0070	.0034	.0020	.0016
	1/50 = .02	.0328	.0287	.0020	.0021
	1/25 = .04	.0810	.....	.....	.....
	1/10 = .1	.1180	.....	.....	.....
	1/5 = .20	.2220	.....	.....	.....
	1/2 = .50	.4970	.....	.....	.....
	1 = 1.0	.8460	.....	.....	.....

Shutter efficiency and the mathematics involved will not be dealt with in this paper. It is proposed in the near future to make a study of the influence of the various types and number of shutter leaves upon the efficiency and illuminating power of the shutter. The various driving mechanisms will be studied (*i.e.*, air, spring, and gear-driven) with a view to finding the most satisfactory method of actuating the shutter. These topics will be dealt with in a later communication.

RESEARCH LABORATORY,
July 28, 1916.

THE PRODUCTION OF LIGHT BY ANIMALS.*

BY

ULRIC DAHLGREN,

Professor of Biology, Princeton University.

THE LUMINOUS INSECTS.

THE insecta share with the higher vertebrata the distinction of having emerged from a life in the water, to live in and breathe the atmospheric air. To be sure a considerable number of animals of other groups have also become land forms, independent of all water but drinking water. Such are found especially in the mollusks, worms and crustacea, but these air-living forms are but a very small proportion of the groups to which they belong and in most cases their life is conditional upon a considerable amount of external moisture.

The insects have become a group of extreme specialization in many directions and among these specializations is the light-producing power. The only other air-breathing organisms that are thus endowed are the fungi, or possibly more species of earthworm and several myriapoda. Even these latter may be in a way classed with the insecta.

The power of lighting is found developed in several families of insects in such a way that it appears to have arisen entirely independently. Thus we find it in some of the most primitive kinds as well as in others of much higher organization, and in this chapter the subject will be discussed in the following groups: (1) Order chilopoda of the class *Myriapoda;* (2) order collembola of the sub-class *Apterygota;* (3) order diptera of the sub-class *Pterygota;* (4) in several doubtful cases in which the luminosity may be due to external causes. In a succeeding part it will be discussed in the groups of coleoptera of the sub-class *Pterygota.*

The myriapoda are elongate animals of a varying number of segments. It is typical of them that they possess a number of integumentary glands secreting fluid materials that are discharged and used outside of the body. Some of these glands are unicellular, others resemble the typical crustacean integumentary gland,

* Continued from page 843, vol. 181, June, 1916.

while in *Julis* the structure is sac-shaped. All these open through one or more pores in the side of each segment.

The substances secreted vary in a wide degree and they are all very highly specialized. Some produce odors, others poisons (as hydrocyanic acid in *Julis*) while in several species a photogenic material is produced that can be discharged and will then give light. It seems probable that in these forms and in the luminous earthworms we have the only examples of organisms that discharge a luminous substance into the air; most air-living forms burn the luciferin internally.

A great many observations have been made on this phenomenon, many of them very old and some so fragmentary or inaccurate that they have little value. We may divide the more careful of these records into four possibilities: First, those cases in which the myriapod had been eating or rubbing against the luminous mycelium of some fungus; second, the records that appear to show that the light came from a material secreted in the intestine, and that it was discharged from the posterior opening of the digestive tract at the time of illuminating; third, we have those cases where the light substance is reported to come from the lateral integumentary glands before spoken of; fourth, and last, some observers have seen the light, when stimulated, spread over the entire surface of the body.

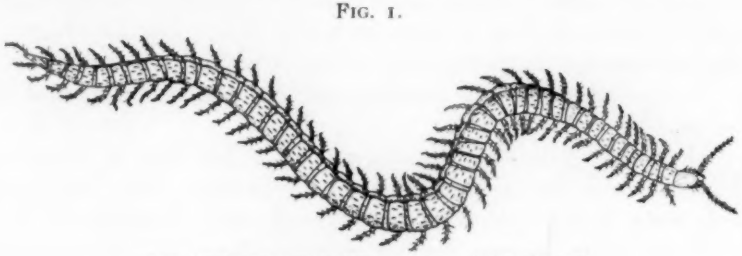
The luminous forms appear to be confined to some members of the order *Chilopoda*. When, however, so well known an observer as Molisch describes a luminous Chilognath we must feel sure that light was seen and this case seems to be one that would come under our first group; seems that the animal had eaten or become entangled in some way with portions of some luminous fungus. This idea becomes more certain when it is known that other specimens of this unnamed species were found to be without light even when strongly stimulated.

As an example of the second kind of observation we may record the report of Du bois who found a specimen of *Scolioplanes* (Fig. 1) under decaying leaves near Heidelberg and saw the luminous material issuing from the anal opening. He later described it as appearing in the same way from *Geophilus electricus* (Fig. 2). Macé described the luminous secretion as issuing from several large glands on the posterior end of the body. This view was also held by several other observers.

Thomas found a species of *Geophilus* crawling on a woodland path in the dark and gives us a very clear and definite account of the lighting process. The animal was being attacked by a number of ants that were biting it and trying to hold it back by seizing its legs and sides. The Geophilus was throwing out masses of a slimy light material from the sides of all its segments and the material was sticking to the jaws and bodies of the ants. They appeared to suffer from its contact and let go, running aimlessly in its wake, showing as moving points of light in the rear of the brighter millipede.

Audouin and Brodhurst observed *Scolioplanes crassipes* lighting and leaving a luminous trail on the ground. They also observed the light to spread all over the surface of the body when the living animal was disturbed and stimulated mechanically.

FIG. 1.



Line drawing of *Scolioplanes crassipes*. (After Brown.)

The above observations, most of them old and casual, show several points that we must read between the lines. First, we can no longer doubt that some individuals of several species *do* light at times. Secondly, the light is thrown off from the body and can be seen to continue to shine on the ground over which the creature crawls, on the enemies that attack it and on the fingers of those who handle it.

What we must look for now is some careful investigation of the best examples of the luminous forms by a careful and trained observer who can decide several questions that have been raised somewhat as follows: First, is there a species all of whose members of adult age and of either one sex or both will light consistently upon a definite stimulation, either throughout the year or at some definite season, as the breeding season, the cold or warm season or the wet or dry season? Second, the position and structure of definite glands and gland cells must be shown

and the mechanism by which the light material is ejected. Our staining methods will do a great deal toward showing luciferine granules in the cells of such glands.

The two best studied forms so far are *Scolioplanes crassipes* from continental Europe and *Orya barbarica* from Northern Africa.

Scolioplanes crassipes (see Fig. 1) is found in many parts of Europe and in consequence is often seen by scientists in its native habitat where any light powers would be more easily observed. We have a considerable number of positive records of light-production as also a perhaps greater number of negative observations. And, to offset the positive records, we must remember two things; this myriapod often lives in the immediate neighborhood of several luminous fungi and it may eat them. Also we know of, or suspect, many other cases of organisms eating fungi or bacteria and shining by their borrowed light. On the whole we must assume for the present that *Scolioplanes crassipes* does light by its own powers but possibly not for the entire period of the year.

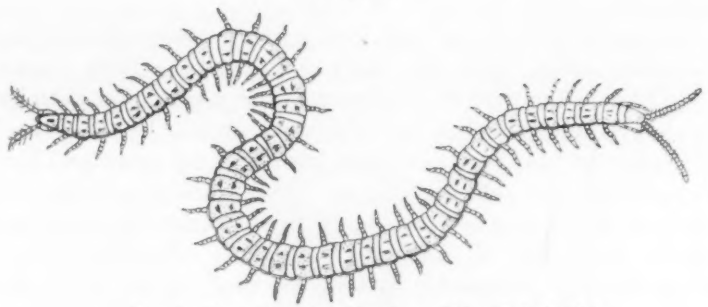
M. Huet, while walking in a garden at La Fere in France at about nine o'clock in the evening of mid-October, 1883, came suddenly upon a space about 40 centimeters square in which he saw, in the darkness, several curved luminous lines which seemed to move. He describes the light as of the color of that which appears on the edge of a burnt piece of paper. As most of us know such a light, it is reddish or orange in color. The following night and other nights he returned but saw no light.

The next year, again in October he visited the garden but saw nothing luminous. Finally, in 1885, on October 17, he came upon a number of the luminous streaks all assembled in a comparatively small space on the same ground. Picking up several in a mass of dead leaves he hastened to the house, dropping all but one on the way. This proved to be a myriapod, called by him *Geophilus electricus* (Fig. 2) and when taken into the dark again it appeared to give off a light, bluish-white in color from the entire surface of its body. The light substance adhered to the fingers when the animal was touched. It was brighter than the light seen by Huet on a dead fish (bacteria) but not so bright as the light of a glow-worm (larva or wingless female of a lampyris).

In later years he searched in the same spot and raked and dug in the humus and soil but saw no more of the luminous forms. This would appear to show that the animals shine only in October or in the fall, also that they had assembled for some reason, possibly for breeding purposes.

R. Du bois searched for the luminous myriapods in many parts of France and Germany. He found them among dead leaves and weeds growing along the railway and near an orchard in the neighborhood of the village of Handschuhsheim near Heidelberg. They were in motion and very bright. It was during a dry spell of weather and in the fall of the year, September or October. Having placed the animals on a piece of paper and examining them carefully with a hand lens he saw the luminous

FIG. 2.



Line drawing of *Geophilus electricus*. (After C. L. Koch.)

material appear as small moist masses that stuck to the paper in the animals' trail and soon ceased glowing and dried up. Each mass was irregularly shaped and appeared to consist of very fine particles, like the finest sand, held together by a tenacious mucus. When attempting to remove some of the dried material he accidently pulled out some of the lower digestive tube and saw luminous material upon or in it. He took this to mean that the material comes from the intestine or some of its glands but did not mention that it might have come from integumentary glands opening on the animal's outer surface and bound mechanically to the tissues of the intestine which is large and nearly fills the body at this point.

Besides emitting a luminous substance the creature had a glow that seemed to come from an internal luminosity and to be continuous. This weaker glow was visible along the sides of the

body and would seem to indicate the presence of luciferine in an active state in the integumental glands.

Du bois was not able to find by dissection any specific light tissues and came to the conclusion, in this paper at least, that the presence of light was accidental and due to some unusual or abnormal physiological condition. He did not attribute it to parasites (bacteria or fungi) or to materials eaten. He did find, by microscopical methods, certain intestinal cells that seemed to be "degenerating" and that contained granules similar in size and form to the granules that appear in the discharged secretion.

Another observer found the millipedes crawling in the superficial cracks and depressions on the trunk of a pear tree in his garden one damp warm night. They shone as streaks of light and their presence in some numbers on one tree would point to the breeding time.

In conclusion we may say that none of the studies of light productions made on *Scolioplanes crassipes* have been complete or satisfactory but that the existence of the power appears to have been definitely established and the work should be taken up by some one who has the opportunity presented by more and better material than has yet been found. The interesting form *Orya barbarica* was discovered to be a light-producing form more recently than was *Scolioplanes*. Raphael Blanchard and J. Gazagnaire first observed it lighting in April and in May respectively of the year 1888, at El Kantara and at Nemours in Northern Africa.

Professor Du bois, not being able to secure a sufficient supply of *Scolioplanes*, went to Africa (Algeria) in 1892 for the purpose of studying *Orya* and collected them, with no apparent difficulty, in the lighting condition. He observed that the light secretion was thrown off from the ventral surface of the animal as a slime that rapidly dried on the hands. Having cut and stained sections of the creature's body, he discovered glands in the integument. These glands possessed ducts that opened on the sternal and episternal plates of the segments. From these came a substance that was yellowish in color and with a peculiar odor of its own. The glands were pyriform in shape and were unicellular, evidently modified cells of the hypodermis. In their cytoplasm could be seen granules of a rounded oval shape and these same granules were also seen in the discharged secretion.

The granules were soft and in the center of each was a fluid-filled space in which appeared a single refractive point or small speck. The material of the granule appeared to be a fatty substance but failed to stain black in osmic acid as a true fat would. In response to rough tests it appeared to be a protoplasm or albuminoid.

Some of the freshly discharged material was placed on a glass slip under the microscope and, while still glowing, was examined with high powered lenses. As the light glowed the refractive speck was seen to develop into a crystal or group of crystals that continued to grow in size as the light continued to be emitted. It is well known to chemists that the crystallization of many substances is accompanied by light and Du bois decided that the light from *Orya* was a crysto-luminescence of this process. He even went so far as to conclude that this was the origin of the light in all luminous forms and to give up his theory of the presence of a catalytic agent, luciferine, although, he subsequently reconsidered this idea, his greatest contribution to the question of the theory of light production in animals. Such a crystallization may be the origin of animal light with the crystals so small that they are not visible. And the catalyzer may still be necessary for this particular process of crystallization.

THE COLLEMBOLID INSECTS.

This primitive order of insects (Fig. 3) is distributed all over the world and is best known to the general observer in two forms that come into our life, the " spring-tails " or " silver-fish " that occur in books, old papers and any other place in the household where they can find paste or glue to eat; also as the small blue-black forms that live on the beaches of both fresh and salt water where they have a curious habit of congregating in masses on the surface of tide pools and other small beach pools. None of these two kinds are luminous, however, but are noticeable on account of their comparatively larger size.

The larger part of the group are of extremely minute size and live on the leaves of living plants and among masses of dead leaves and wood in the forests and meadows where they can be damp and secure from disturbance by their enemies. Some are so small as to be scarcely visible to the naked eye. It is among these *Thysanura* that light-producing members have been seen

by several observers among whom are Allman, Lubbock, Tullbirg, Heinrich, Molisch, Du bois, Ludwig, Templeton and others.

Allman seems to be the first (in 1850) to have observed light in a species, *Amphorura finetaria*, in the neighborhood of Dublin in the month of February. Mangold uses the name *Anuphorus* or *Lipura finetaria* for this species. Allman found the creatures in thick heaps of manure which are abundant in that locality.

FIG. 3.

Figure of a poduran. (After Guérin and Percheron.)

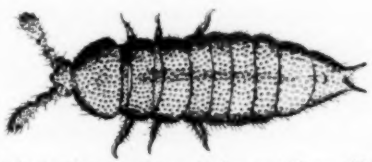
Du bois observed and described the same phenomenon in the neighborhood of Heidelberg in 1886, while he was searching in the night time for luminous myriapoda. Fig. 4 shows the form that he studied, *Lipura noctilnea*. He found them in the same hop field and same masses of dead leaves in which the luminous myriapoda were found. This is important as showing that they were exposed to the same chances of infection with any luminous mycelia growing in their surroundings that the myriapoda were.

Also the light of the myriapoda might have come from eating the bodies of the podurans. This seems rather unlikely, however, as the digestion process would in all probability have destroyed the light cells very quickly.

The insects appeared in the freshly turned-over humus as a large number of tiny blue-green stars or points of light. They were so small that they could not be seen at any distance. One had to look from a distance of not more than forty centimeters in order to see them clearly. The general impression that they gave was much that of seeming sea water with its numbers of noctilucas or other peridinidæ.

Under a magnifying glass the podurans were seen to give off the light from all over their bodies. They were only 2-3 mm. long and slender. This light was continuous, an important point,

FIG. 4.



Drawing of the luminous poduran *Podura noctiluca*. (After Henneguy.)

and was augmented by mechanical and other stimulations. When the bodies were crushed it appeared that the entire mass gave off light. While it is true that it appeared to do so, it is more probable that the appearance was due to a mixture of luminous tissue with the non-luminous portions of the body. At the same time it tends to show that the light organ is large and extensive in proportion to the size of the body.

An application of litmus paper to the mass showed an acid condition. This might be due to a number of parts and does not seem to signify much in this particular case. The same seems to apply to Du bois' second experiment of placing some of the material on the tongue when distinctly acid sensations were experienced as well as a strong odor. The odor at least most probably came from some scent glands rather than from the light organs.

Lipura armata was studied also but gave no sign of luminous activity.

Upon dissecting the body of a luminous form with needles, it was observed that the tissues showed lumps of a peculiar re-

fractive appearance. Under crossed Nicols prisms these are described as giving the same appearance as the luminous tissues of other animals. Also they contain granules resembling the granules of light cells in the fire-flies. It should be easy to determine by microscopic methods if these are the light organs or not. This does not appear to have been done.

Ludwig discusses Du bois' paper and the possibilities of finding the light power among other members of the podura. Having collected many species himself he suggests that they be studied again by some one with reference to a possible luminosity. Many of the species live on plant leaves. In this regard the writer calls to mind the story of a friend who said that on his way home one night he had occasion to urinate on some weeds by the wayside. When drops of the fluid fell on the leaves a number of bright luminous spots appeared which might have been some luminous podurans stimulated into activity by the acid fluid.

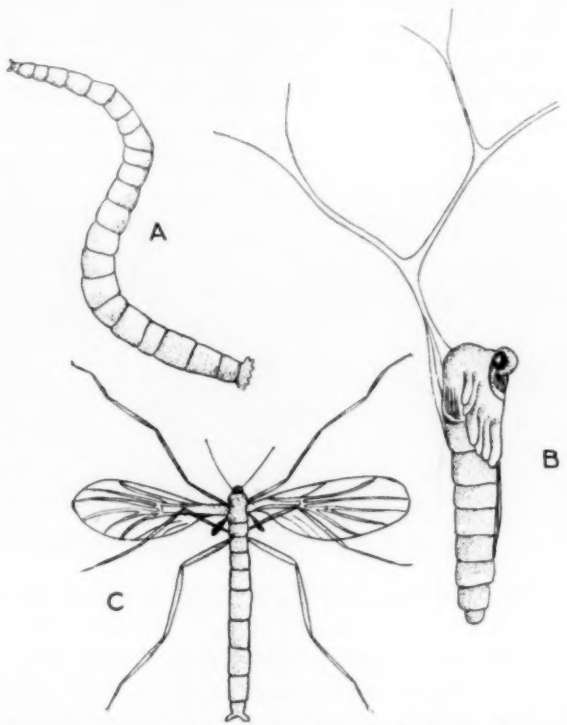
TIPULID FLIES.

While our scanty and somewhat fragmentary evidence as to the lighting of some of the preceding forms leaves us in partial doubt as to their autogenous light production, we find in the case of *Bolitophila luminosa*, a tipulid fly, that the evidence is complete and well authenticated as to their lighting power. This fact has been observed by Meyrick, Hudson, Cheesman and other New Zealand naturalists, and, during a trip to the caves of New Zealand by Conklin, Wheeler and other members of the scientific groups visiting that country at the invitation of the Royal Society of London in September, 1914. Wheeler and his pupil, M. Williams, published an account of this form in 1915 in the Journal "Psyche," dealing principally with the light organ as found in the adult larva of this form. From this and the preceding accounts we find ourselves in possession of a fairly good knowledge of the subject. Fig. 5 shows the larva pupa and imago of this fly.

The larva lives in caves or under the hollow banks of streams in dark woods. It is of the form and general appearance of most fly larvæ, with a pointed head situated on the thinnest end of the elongate body and with the chitin of the jaws and surrounding mouth-parts showing a brown to black color, the only color visible on the whitish, translucent body.

The larvæ live on a series of thin, moist, glutenous threads, spread as a scanty net in connection with the surface of the rocky or hard earthen bank of the cavern which they inhabit. According to Hudson one strand of the net is longer and straighter than the rest and forms an axis of the greater length of the web. The larva spends most of its time on one end of this main axis with its

FIG. 5.



A, larvæ; B, pupa, and C, imago of the tipulid fly, *Bolitophila luminosa*. The pupa is suspended from the glutenous net that it constructed as a larva. (After Hudson.)

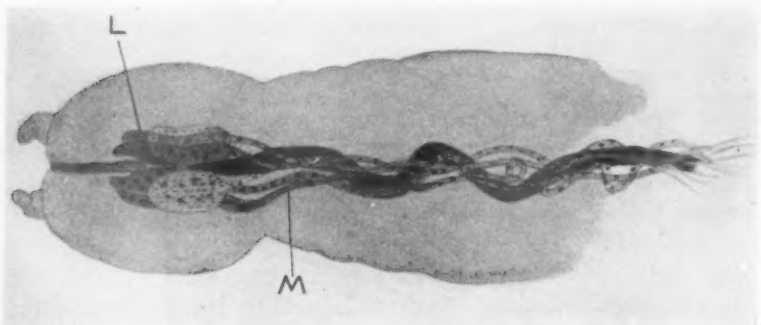
body partly inside of a burrow or cleft in the rock. It is said to retreat into this cavity when disturbed.

As to the food eaten by the larvæ, it was thought by Hudson to consist of the dead or low organic forms of life in its surroundings, but Wheeler showed that the larvæ catch living insects in the sticky web and use them for food as Meyrick has stated. These larvæ are quite numerous in some of the caves and tunnels and shine like hundreds of bluish-green stars above the observer who

has entered such a place. The light appears to glow rather steadily but is evidently under the animal's control because if disturbed they shine with extra brilliancy for a few seconds and then suddenly shut off the light and retreat from the web into the hole or cleft near which it is built.

Wheeler examined the larvæ in the living state in the tunnels and caves and was able to locate the light organs with a strong pocket lens. The luminous organs could be plainly placed as four thick, parallel rods, closely applied to one another on the ventral surface of the rectum. These rods were in the somewhat dilated, terminal segment, identified by Wheeler as the eleventh abdominal segment because it bore a pair of small jointed cerci. The luminous rods were parallel, slightly curved and ran parallel to

FIG. 6.



Dissection of the posterior part of the body of the larva of *Bolitophila*. Seen from ventral surface. L, luminous organ; M, Malpighian tubules originating from intestine. (After Wheeler and Williams.)

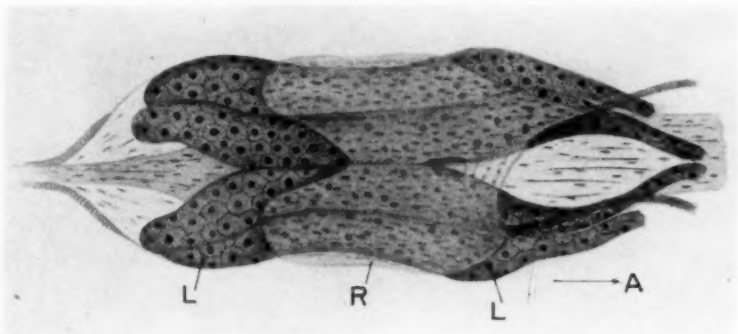
the intestine and the length of the larva. They were arranged in the form of a plate in the longitudinal as well as the lateral direction. The slight curve of the rods rendered this plate somewhat convex on its ventral surface and concave on its dorsal surface. They gave off a bluish-green light, much more intensely from the dorsal surface than from the ventral. The reason for this will appear later.

Wheeler and Williams dissected some of these larvæ and sectioned and stained others. This showed that the four rod-shaped light organs were the distal ends of the four long, coiled malpighian tubules found in all insects as the excretory organs. They are tubular invaginations of the simple epithelial wall of

the lower intestine and vary in number to a considerable extent in the different species of insects, six and eight being common numbers, while they may be as few as two or extend into very large groups. In the diptera there are usually four.

In *Bolitophila* these four tubules are given off from a fairly anterior point (see Fig. 6) and, after running forward a short distance, turn and go posteriorly, having a curved path with several loops that straighten out when the creature extends its elastic body. The tubules, of generous size at their point of origin, widen their diameter somewhat during their anterior course and then gradually become smaller as they pass posteriorly. As they

FIG. 7.



Enlarged view of luminous organ seen from ventral side. R, reflector; L, luminous organs. A, anterior direction. (After Wheeler and Williams.)

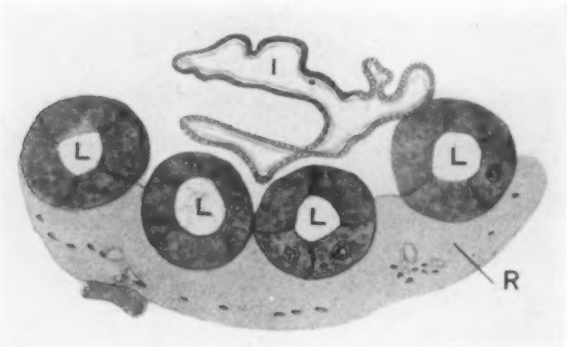
narrow they assemble on the ventral side of the gut, finally becoming very narrow and arranged horizontally just before they suddenly widen again into the four short, thick rods that form the light organ. Fig. 6 shows these, and Fig. 7 shows them on a larger scale.

Sections of the various parts of the tubule show it to be a typical insect excretory organ with the large, fleshy cells and striated distal border lining a wide, flat, narrow lumen. Sections down in the light-producing portion show that this structure has been substantially changed although both cellular wall and lumen are continuous with those of the excretory portion of the gland. The cytological structure of this light-producing portion has not been as closely studied as is desirable. It can be said, however, that the cytoplasm is secreting large masses of a granular material and that these granules are undoubtedly granules of luciferine,

or, as E. N. Harvey has recently named it for reasons to be explained in a following chapter, photophelein.

Of great interest is a mass of modified connective-tissue found on the ventral surface of the plate-like group of four rod-shaped tubes. This tissue is the reflector, as is evidenced by the fact that the light appears much brighter when seen from above. It has not been studied sufficienty to show what material has been developed by the cell to perform the reflecting function. If we refer to the fire-flies (Lampyridæ) we may suppose that crystals of some urate are thus used but further studies may show some

FIG. 8.



Transverse section of luminous apparatus of larva of *Bolitophila*. L, luminous organs; I, intestine; R, reflecting tissue showing tracheal tubes (hollow spaces) and muscle fibers (dots); (After Wheeler and Williams.)

other substance. The reflection is not as complete as in the lampyridæ and this appears to point to some important difference. The reflecting layer does not completely cover the light glands on their ventral surface as Fig. 8 will show.

The tips of the luminous portion of the malpighian tubules are not complete, the lumen being separated from the body cavity only by a thin plate of tissue which, owing to its lack of cytoplasmic body, cannot have any photogenic function.

Not only is the larvæ of this fly luminous, but also, as Hudson has shown us, the pupæ and the imago show a light. Unfortunately we have no histological studies as yet published that indicate the structure of the light glands in these subsequent forms. Very possibly the same malpighian tubules are retained to perform the function, but it is also quite possible that another and entirely

different set of cells are developed as light organs. As will be seen in the next chapter this occurs in our lampyridæ and most probably also in *Phengodes* and *Pyrophorus*. The light appears in the same part of the abdomen in both pupæ and imago as it does in the larva.

CHIRONOMID FLIES.

Another family of tipulid flies, the chironomidæ, of which there are over 500 species in Europe alone, show some members which are said to be luminous (see Fig. 9). Osten Sacken de-

FIG. 9.

Drawing of a chironomus fly. (After Miall.)

scribed such forms in 1878 and Brischke in 1876. While Tarnani has discussed them in 1908, his paper is unfortunately written in Russian and was inaccessible to the writer who gets his information from Schmidt's careful paper published in 1895.

Schmidt visited Lake Issyk-Kul in Russia and a lake near Prshewalsk in the summer of 1894 and found there flies on the wing and exhibiting their light. Swarms of them were hatching from the water and flying over the beaches. More than one species was showing the light and three such were identified as *Chironomus intermedius*, *C. plumosus* and *C. tendens*. Not all the members of any one species showed the light but only a limited proportion. The light thus shown was not a flashing one, but a continuous light that appeared to shine from every part of the body from some internal source.

This seems to point to an artificial condition rather than to an autogenous light production. Further, this view is supported by the fact that the luminous individuals were distinctly sluggish both on the wing or when they alight on wood or shrubbery. They were prone to alight and remain quiet while their non-luminous fellows were flying. The light was surprisingly bright, being compared to that of a fire-fly.

We evidently have to do here with a case of disease, probably caused by fungus or bacteria. One thinks at once of the luminous *Talorchestia* mentioned in the chapter on crustacea in which we have proof that bacteria in the blood and digestive tube are the source of the illumination. There is the difficulty here, however, of imagining any luminous bacteria that live in or around a fresh water locality. To be sure they would find enough sodium chloride in the tissues of their host to be able to illuminate and, in the intermediate stages, they might breed and live in the non-luminous condition on other media found in or near the waters of this region. Other localities are known in Germany where these species of the chronomidæ are common, but where no light has been observed in connection with their life history.

The larvæ live in mud and vegetable débris on the bottom of the ponds and lakes. The flying was in early summer.

Eaton has mentioned a luminous mayfly from Ceylon, and Gummerthal a luminous fly larva from Russia, but these reports require further investigation and study.

Autogenous light has been attributed to several other insects. Persistent reports of the luminosity of the lantern-fly, *Fulgora*, by Bowring, Brauner, Distant, Evans, Gounelle, Hancock, Hoffmansegg, Moufflet, Smith, Wesmael and Westwood have been published. While many have asserted that the light has been seen by other (mostly non-scientific) observers, the question is not settled, and certain other observers have tried and have failed to see it. The idea seems to have arisen, not from seeing light, but from the fact that a large hood on the head is shaped like a lantern in which some ignorant observer has imagined that he saw a light, being prompted to this idea by the name.

The larvæ of a moth or butterfly has been reported as luminous by Boisduval, and other observers have reported light as coming from other beetles than the elatyridæ and lampyridæ.

(To be continued.)

NOTES FROM THE U. S. BUREAU OF STANDARDS.*

A STUDY OF ELECTROMAGNET MOVING COIL GALVANOMETERS FOR USE IN ALTERNATING CURRENT MEASUREMENTS.[1]

By Ernest Weibel.

[ABSTRACT.]

THE increasing use of alternating current bridge and potentiometer measurements emphasizes the need of a detector or galvanometer with characteristics similar to those of the sensitive galvanometers used in the corresponding measurements with direct current. The vibration galvanometer is fairly satisfactory at commercial frequencies and at telephonic frequencies the telephone receiver is used, but in both cases the performance fails to equal that of the direct current galvanometer. This paper gives the results of a study of the electromagnet moving coil galvanometer which has led to the construction of instruments with sensitivities much greater than those previously obtained and equal to those of the best direct current moving coil galvanometers.

The theory of the instrument is developed and is based on the equation of motion which is deduced by considering all of the torques acting on the moving coil in the alternating magnetic field. The equation of motion is first expressed in terms of the intrinsic constants (the moment of inertia, the moment of damping, the moment of restoration and the moment of displacement), and the deflection, velocity, acceleration and current in the moving coil. The current is then known from the resultant electromotive force in the moving coil circuit and the moving coil circuit constants. It is necessary in computing the resultant electromotive force to consider not only the impressed but also the induced electromotive force. This induced electromotive force is in part due to the motion of the coil in the magnetic field, causing electromagnetic damping, and in part due to the alternation

* Communicated by the Director.

[1] Scientific Paper No. 297.

of the flux linking with the coil, causing a current which results in a control torque in addition to that of the suspensions. It is found that the motion may be underdamped, aperiodic, or overdamped, depending upon the magnitudes of the intrinsic constants and the constants of the moving coil circuit. In case of a sinusoidal magnetic field and a non-inductive moving coil circuit the performance is analogous to that of the permanent magnet moving coil galvanometer for direct current. The operating constants of importance are—the period, the external critical resistance, and the sensitivity. The deflection is proportional to the component of the electromotive force in phase with the magnetic field. In order, therefore, to be sure that no deflection means no detectable electromotive force it is necessary either to know that the electromotive force is in phase with the magnetic field or to change the phase of either the excitation or the current or currents furnishing the unknown electromotive force.

The operating constants are given in terms of the intrinsic constants so that, if these are known, the performance can be predetermined for the conditions of use. A method of measuring the intrinsic constants has been developed. Equations are given for use in the design of instruments to give definite operating constants.

If the moving coil circuit contains reactance the performance of the instrument is changed. The paper shows how the operating constants depend upon the constants of the external moving coil circuit. Condensive reactance lengthens the period and inductive reactance shortens it. These effects as well as the effect of electromagnetic damping increase with decrease of the impedance of the moving coil circuit. It is, therefore, possible to vary the performance considerably by changing these constants and by changing the excitation.

The effects of harmonics in the magnetic field on the selectiveness of the instrument is shown and it is usually possible to increase the selectiveness sufficiently by the use of electrical resonating systems in connection with either the excitation or moving coil circuits.

The paper contains the descriptions and gives the performances of four instruments. The results indicate that the theory as given is fundamentally correct and therefore serves as a good basis for the design and use of instruments of this kind.

THE RECOVERY OF PARAFFIN AND PAPER STOCK FROM WASTE PARAFFIN PAPER.*

By W. H. Smith.

[ABSTRACT.]

A PROCESS is described for the recovery of the paraffin and paper stock from waste paraffin paper, employing a vertical steam boiler, tanks for receiving the paraffin and a beating engine. The waste is pulped in the boiler, with exhaust steam, in order to separate the paraffin from the fibers. After the treatment, the wax rises to the surface and is drawn off with the hot water through a screen, the stock settling to the bottom of the boiler. The stock is transferred to a beating engine and treated with hot water, soap, and turkey red oil, or with caustic soda, depending upon the amount of ink in the material. The turkey red oil assists the residual paraffin to coalesce and rise to the surface. By means of a metal cylinder, internally chilled with cold water, and partly submerged in the hot water of the beater, the paraffin remaining in the stock is readily collected. Paper prepared from the recovered stock was free from wax and satisfactory in every respect. Practically all of the paper stock is recovered, but about ten per cent. of the paraffin in the waste is lost during the process.

TESTING OF CLINICAL THERMOMETERS.

[ABSTRACT.]

THE Bureau of Standards has just completed a revision of Circular No. 5 on the "Testing of Clinical Thermometers." This new edition, which is the third so far, announces the adoption of new regulations, effective January 1, 1917, governing the testing of clinical thermometers. Past practice was to issue certificates containing tables of corrections at four points, 96°, 100°, 104°, and 108° F.; the new certificates will be issued only for thermometers correct within 0°.1 F at normal (98°.6); and 0°.2 at 104°, and will contain the statement that the thermometer is correct within these tolerances.

The circular contains a full description of the method of test-

* Technologic Paper No. 87.

ing clinical thermometers and considerable matter of general interest concerning these instruments.

The question of accuracy in clinical thermometers is obviously an important one. The clinical thermometer bears the same relation to the physician as the weighing scale does to the merchant, but in a way the former is vastly more important, as it has to do with life itself.

It has been estimated that over a million of these little instruments are manufactured each year to replenish the supply, for a clinical thermometer is delicate and usually short lived. Unscrupulous manufacturers, taking advantage of this never ceasing demand, place on the market thousands of unreliable thermometers, which, on account of their cheapness and the fact that their defects are almost impossible of detection, find ready sale.

It is obvious that the Bureau cannot inspect all these thermometers for it tests only those that are voluntarily submitted. This circular calls attention to the fact that thermometers of doubtful accuracy may always be checked at this Bureau, and that when a thermometer is offered for sale with a Bureau of Standards certificate, its reliability can not be questioned. If instruments of a high quality are thus demanded, in time the unreliable article will no longer be manufactured.

NATIONAL ELECTRICAL SAFETY CODE.

[ABSTRACT.]

THE Bureau of Standards, Department of Commerce, has recently published the second edition of Circular No. 54, entitled the "National Electrical Safety Code."

The increasing application of electrical energy for various commercial and private uses brings a rapidly increasing number of persons in contact with or into close proximity to electrical equipment of various kinds. In many cases the persons working on or near such equipment are not familiar with the hazards involved. It is also becoming better appreciated that in many cases such equipment may readily be provided with more adequate protection against accidents than has heretofore been the general practice. The use of safer construction and better insulation methods

has, in fact, been found to be a prominent factor in increasing the use of electricity.

The National Electrical Safety Code has been developed by the Bureau of Standards after some three years of study of the many hazards involved, aided by the active coöperation of the many interests which such a Code affects, including the electrical utilities serving the public and the administrative authorities, such as state utility, accident, and labor commissions, and accident and compensation insurance companies, who are particularly interested in the problems of accident prevention. The Safety Code gives in detail requirements based upon principles recognized as correct in the experience of a great number of public utility companies, the recommendations of inspectors for commissions, municipal authorities and insurance companies in their studies of accident prevention, as well as those indicated by an analysis made by the Bureau of a great number of electric accidents reported from all parts of the country. In addition to those rules which appear as requirements, there are many which are merely recommendations, but which will very often be observed where the maximum degree of safety is desired.

The Safety Code is subdivided into four principal parts. These several parts contain rules and recommendations applying to the several phases of the electrical industry, as follows: Part 1, Electrical supply stations for the generation of electrical energy; Part 2, Overhead and underground lines for the transmission and distribution of electrical energy and intelligence; Part 3, Utilization equipment for the conversion of electrical and mechanical energy, and for light, heat, and electrolytic processes; and Part 4, rules to be observed in the operation of electrical equipment and lines. There is also a section on the methods of protective grounding. These rules apply generally without regard to whether the system supplies electrical energy commercially or is a portion of a manufacturing plant.

In introducing the National Electrical Safety Code the Bureau of Standards earnestly recommends that it be used on trial for a period of a year or more before it is enforced in a formal manner. During such period of actual trial and study on the part of administrators and those to whom the rules apply, it will be possible to observe how it operates in practice, and in what respects it should be modified. Constructive criticism is requested in order

that subsequent editions may be made of the greatest practical value to the electrical industry.

SPECIFICATION AND TESTS OF THE TRANSPARENCY OF PAPER AND TRACING CLOTH.

THE Bureau of Standards, Department of Commerce, has just published a Circular under the above title (Circular No. 63). It describes a method of quantitatively specifying transparency for practical purposes, states the form of the specification, and gives a description of the apparatus used to make measurements.

Aluminum Castings. P. E. MCKINNEY. (*Proceedings of the American Institute of Metals,* September 11–15, 1916.)—It is a well-known fact that pure aluminum is entirely too soft to produce satisfactory castings for most purposes, and it is the universal practice to stiffen up the alloy with some hardening element. Probably the most widely used hardener for aluminum is copper which is used at the rate of about eight per cent. of copper to ninety-two per cent. of aluminum. Zinc and tin are also frequently used as hardeners. The use of these hardeners is attended with some well recognized objections. In the first place, the addition of eight to ten per cent. of hardener partially defeats the purpose of using aluminum in that the specific gravity is materially increased. The hardened metal, while fairly strong, has a decided tendency to brittleness and the alloys are in most cases less resistant to corrosion than either of the component metals. Hot shortness, in the case of intricate castings, is another feature attendant to the use of these hardeners.

In the 9th Annual Report of the Alloys Research Committee, Dr. W. Rosenhain and Mr. F. C. A. H. Lentiberry have published some very interesting data on the influence of manganese on aluminum alloys, which demonstrates beyond a doubt that these combinations have great promise in the production of light alloys. Various combinations containing manganese, with or without copper and with a minimum aluminum content of ninety-five per cent., have been used in actual foundry practice for the past two years with most gratifying results. The use of manganese in relatively small quantities hardens and strengthens the alloy without destroying its ductility as is the case with copper or zinc. The machining properties are excellent and the comparatively small amount of hardener used makes possible a specific gravity in the finished alloy of 0.35 to 0.40 less than that of the ordinary No. 8 alloy. When properly made, these alloys are practically free from hot shortness and the most intricate castings can be produced with comparative ease.

NOTES FROM THE RESEARCH LABORATORY, GENERAL ELECTRIC COMPANY.*

THE EVAPORATION, CONDENSATION AND REFLECTION OF MOLECULES AND THE MECHANISM OF ADSORPTION.[1]

By Irving Langmuir.

PART I.

It is suggested that the reflection of mercury atoms described by Wood (*Phil. Mag.*, 30, 300 ('15)) can be attributed as well to condensation, with subsequent reëvaporation when the plate is sufficiently hot. The distinction between the two explanations, which will become apparent at intermediate temperatures, consists in that if it is reflection, the number leaving the plate will always be proportional to the number striking, but if it is reevaporation the number can never exceed the normal rate of evaporation of mercury in a perfect vacuum.

Experiments are described which seem to indicate that molecules and atoms of all kinds show little tendency to reflection from solid surfaces. Of metal vapors condensing on surfaces of the corresponding metal, not over one atom per thousand is reflected. Molecules of permanent gases striking surfaces covered with adsorbed films of gas molecules give some evidence of reflection which may reach 81 per cent. for hydrogen from a surface covered with hydrogen at high temperatures. This appears to be the maximum possible and the amount for other gases is less than 50 per cent. no matter what the nature of the solid surface.

Evidence is drawn from the results of experiments upon the rate of evaporation of tungsten filaments, the vapor pressures of platinum, molybdenum, and silver, the electron emission of tungsten. It has been further shown by experiments on the "accommodation coefficient" of hydrogen that the reflectivity changes only slightly with temperature.

A statistical consideration of heterogeneous chemical reactions has shown that the fraction of the number of oxygen molecules striking heated tungsten or molybdenum filaments which under-

* Communicated by the Director.

[1] *Physical Review*, **8**, 149-76 (1916).

go chemical reaction increases rapidly with temperature, becoming 0.4 at 3000° K., and apparently reaching at higher temperatures a limiting value of 0.7. Hence the reflectivity cannot exceed 30 per cent., and probably the small values of the fraction at low temperatures is due to an inactive condition of the surface rather than to a higher reflectivity.

Hydrogen at pressures so low that the normal free path is several meters, converted into atomic hydrogen by contact with heated tungsten, can diffuse long distances through glass tubing at ordinary temperatures but cannot pass even short distances through tubing cooled by liquid air.

Study of the reaction between hydrogen and oxygen on a platinum surface has shown that here the reflectivity of oxygen molecules cannot exceed 47 per cent. and of hydrogen 59 per cent., even at 900° K. The study of a large number of other heterogeneous reactions seems to bear out the conclusion that the fraction of the gas combining approaches unity except in cases where the surface of the solid is largely covered with inactive material.

A detailed mathematical consideration of the energy relations involved and of certain other atomic properties develops a method for calculating the maximum amount of reflection and it is concluded that this can in no case exceed 99 per cent., and is in all probability not more than 90 per cent.

THE CONSTITUTION AND FUNDAMENTAL PROPERTIES OF SOLIDS AND LIQUIDS.[1]

By Irving Langmuir.

PART I. SOLIDS.

THIS article is too detailed and specific for abstracting. The following is the author's summary:

1. The work of the Braggs on crystal structure is reviewed from the viewpoint of the chemist and the relation of this work to theories of chemical constitution, such as those of Werner, Stark, J. J. Thomson, and Lewis, is discussed in detail.

2. It is concluded that the substances whose structures have thus far been studied by the X-ray spectrograph are not repre-

[1] *Journal of the American Chemical Society*, **38**, 2221–95 (Nov., 1916).

sentative of compounds in general. Only polar compounds have been studied.

3. Solid polar compounds are, in general, built up of atoms bound together by secondary or residual valence. The whole crystal must be regarded as a single molecule.

4. Solid non-polar compounds consist in general of "Group Molecules," in which the atoms are usually held together by primary valence. These group molecules in turn are bound together by secondary valence to form a large "Crystal Molecule," which includes the whole solid mass.

5. There is no present justification for dividing interatomic (or intermolecular) forces into *physical* and *chemical forces*. It is much more profitable to consider all such forces as strictly chemical in nature. Evaporation, condensation, solution, crystallization, adsorption, surface tension, etc., should all be regarded as typical chemical phenomena. The object of this paper is largely to show that *chemical knowledge already available* is directly applicable to the study of these phenomena.

6. From a consideration of such properties as specific heat, compressibility, coefficient of expansion, etc., it is concluded that collisions do not take place between the atoms of solids, but that these move about equilibrium positions under the influence of both attractive and repulsive forces.

7. The "time of relaxation" of the atoms of solids is calculated approximately from the heat conductivity and is found to be of the order of 10^{-14} to 10^{-7} seconds. An independent method by which the "time of relaxation" can be calculated from the rate of evaporation of a substance in vacuum gives substantially similar results. Thus the time necessary for an atom of a solid to reach thermal equilibrium with its neighbors is very small compared to the time necessary to make a single oscillation about an equilibrium position. The "oscillations" are thus extremely strongly damped.

8. Since solid substances in general are held together by secondary rather than primary valence, there are few limitations to the number of compounds that can exist in the solid state. Most of these compounds do not show a composition which could be predicted from the ordinary rules of valence. Metallic compounds, minerals, solid solutions and glasses are discussed from this point of view.

9. By considerations based largely on the compressibility, it is concluded that the attractive forces between atoms usually reach a maximum intensity when the distance between adjacent atoms in solids is increased by about 0.6×10^{-8} cm. (10–30 per cent. of the normal distance between atoms).

10. Since energy must be expended in breaking apart a solid, the surface of solids must contain more potential energy than do the corresponding number of atoms in the interior. Since this potential energy is probably electromagnetic energy in the field between atoms, the interatomic forces are more intense on the surface than in the interior. This intense field of force (unsaturated chemical affinity) is one of the causes of the phenomena of condensation and adsorption.

11. Because of the small time of relaxation and because an atom approaching the surface is attracted by many, but later is repelled by few atoms, it follows that the surfaces of solids are almost wholly inelastic in regard to collisions of molecules impinging on the surface. There is also a great deal of experimental evidence of this inelasticity. As a result, nearly every molecule or atom striking a solid surface condenses, no matter what the temperature may be. While condensed it is held to the surface by forces quite similar to those holding solids together (either primary or secondary valence). At high temperatures evaporation may take place almost immediately after condensation, but at lower temperatures, the condensed atom or molecule may remain indefinitely.

12. The phenomena of condensation and evaporation (sublimation) of solids are discussed at some length. In general, the rate of evaporation (m) of a substance in a high vacuum is related to the pressure (p) of the saturated vapor by the equation

$$m = \sqrt{\frac{M}{2\pi RT}}\, p.$$

Red phosphorus and some other substances probably form exceptions to this rule.

13. The mechanism of the dissociation of a solid, such as $CaCO_3$, is discussed. It is shown that when, according to the phase rule, separate phases of constant composition are present, the reaction must take place exclusively at the boundaries of these phases. This kinetic interpretation of the phase rule indicates

clearly the distinction between reactions in which solid solutions are formed and those in which separate phases appear. This theory offers a ready explanation for the fact that hydrated crystals frequently fail to effloresce unless scratched and for the fact that thoroughly dehydrated substances often absorb moisture with great difficulty.

14. Adsorption is a direct consequence of the time lag between the condensation and the subsequent evaporation of molecules. The adsorbed substance may be held to the surface either by secondary or primary valence. In either case it is profitable to regard the phenomena as chemical in nature. A large number of experimental results are given which prove conclusively that adsorption is very frequently the result of the strongest kind of chemical union (primary valence) between the atoms of the adsorbed substance and the atoms of the solid.

15. It is shown that the action of a typical catalytic poison depends on the formation of a very stable film one atom deep over the surface of the catalyzer. The chemical activity of any solid surface depends upon the nature of, the arrangement of, and the spacing of the *atoms* forming the surface layer. There is a very close relation between the chemical activity of a surface and the electron emission from it (either thermionic or photoelectric emission).

16. A brief quantitative development of this theory of heterogeneous reactions is given. A " law of surface action " analogous to, but different from, the " law of mass action " is proposed. This theory is in accord with and affords an explanation of Reichinstein's " Constant Sum Hypothesis." An outline is given of the application of this theory to heterogeneous gas reactions and to enzyme action.

The second part of this paper will deal with the Structure of Liquids with particular reference to surface tension phenomenon. It will be shown that the surface tension of organic fluids is a characteristic *chemical* phenomenon. It depends particularly upon the *shapes* of the group molecules and upon the relative intensities of the chemical activity of different portions of the molecules. A method will be described (together with experimental data) by which the *cross sections, lengths* and other dimensions of the group molecules of liquids may be determined.

Arch Centers Suspended from Old Plate Girders. ANON. (*Engineering News*, vol. 76, No. 18. November 2, 1916.)—In the construction of a reinforced-concrete arch bridge crossing over the Lackawanna R. R. at Millburn, N. J., the right-of-way was kept clear of falsework by suspending the arch forms from plate girders spanning the abutments. This part of the line is subject to very congested commuting traffic in morning and evening on all three of the tracks, so that it was highly desirable that the usual falsework posts be omitted. Rather than use steel arch centers (which would reduce the top clearance to dangerous limits) or attempt to space falsework posts for clearance, the engineers decided to suspend the forms from above, utilizing an abandoned plate-girder bridge that could readily be brought to the site.

The arch is on a skew with a single rib carrying an earth fill between gravity spandrel walls. The abutments and the arch were constructed first, the arch being carried up to the limit of its overhang on segmental forms supported from struts well outside the outer tracks. The arch rib was finished here with jogged skewbacks normal to the time of thrust. The intervening section, 45 feet span, was carried by the suspended centering. On the abutments were then placed four plate girders. Each girder was about 60 feet long and 6 feet deep. The centering consisted of 3 x 3 inch angles shaped to the arch curve carrying 2 x 2 inch transverse lagging supported by ¾ inch rods. The suspender rods were covered with tubing so that they could be readily removed when the arch concrete had reached a proper set. The proper curve could be readily controlled by screws at the top of the rods. The method proved very successful, and more economical than using the steel ribs embedded in concrete, considering the high cost of such steel at the time this work was done.

Use of Diatomaceous Earth in Sugar Refining. ANON. (*U. S. Geological Survey Press Bulletin* No. 297, November, 1916.)—Diatomaceous earth, which is made up of remains of minute aquatic plants, is a light earthy material resembling chalk or clay. The hardness, the minute size, and the angular shape of its grains make it an excellent metal-polishing agent, and heretofore it has been largely used as an abrasive in the form of polishing powders and scouring soaps. Of late, however, according to the United States Geological Survey, Department of the Interior, the uses of diatomaceous earth have been considerably extended. It is used by sugar refiners for filtering or clarifying; as an insulating packing material for safes, steam pipes and boilers; and as a fireproof building material. In the United States it is used in the manufacture of records for talking machines. In Europe it has been used in preparing artificial fertilizers and in the manufacture of water glass, cements, artificial stone, paper, sealing wax, fireworks, papier-mâché, and other articles. A total of 4,593 tons of diatomaceous earth was produced and sold in the United States in 1915.

THE FRANKLIN INSTITUTE

(*Proceedings of the Stated Meeting held Wednesday, December 20, 1916.*)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, December 20, 1916.

PRESIDENT DR. WALTON CLARK *in the Chair.*

Additions to membership since last report, 8.

Mr. Charles E. Bonine, Chairman of the Committee on Science and the Arts, reported the condition of the work of the Committee.

The following nominations were made for officers and managers to be voted for at the annual election to be held on January 17, 1917:

For President (to serve one year), Walton Clark.

For Vice-President (to serve three years), Coleman Sellers, Jr.

For Treasurer (to serve one year), Cyrus Borgner.

For Managers (to serve three years), G. H. Clamer, Theobald F. Clark, Walton Forstall, Benjamin Franklin, Harry F. Keller, Richard Waln Meirs, George D. Rosengarten, William Chattin Wetherill; (to serve two years), Nathan Hayward.

The Chairman appointed the following members to act as tellers of the election: Messrs. W. N. Jennings, Henry F. Colvin, and Lucien E. Picolet.

The paper of the evening was presented by Mr. Leo Wallerstein of the Wallerstein Laboratories, New York City, entitled, "Enzymes in the Fermentation Industries." A brief outline was given of the nature of enzymes, their physical and chemical properties, their classification, commercial properties, and modes of action. The various manufacturing operations in the fermentation industries, including malting, brewing, and vinegar making, were described, and their dependence on enzymatic action was considered. It was shown how the quality of the finished product depends to a large extent on the various enzymatic actions which take place during malting, mashing, and fermentation. The speaker also described his method of employing proteolytic enzymes for rendering beers chillproof and stable. The subject was illustrated by experiments, specimens, lantern slides, and diagrams.

After a vote of thanks to the speaker, the meeting adjourned.

R. B. OWENS,
Secretary.

COMMITTEE ON SCIENCE AND THE ARTS.

(*Abstract of Proceedings of the Stated Meeting held Wednesday, December 6, 1916.*)

HALL OF THE FRANKLIN INSTITUTE,
PHILADELPHIA, December 6, 1916.

MR. C. E. BONINE *in the Chair.*

The following reports were presented for first reading:

No. 2682.—The Hooven Automatic Typewriter.

Representatives of the Hooven, Owens, Rentschler Company appeared before the Committee and explained the operation of the Automatic Typewriter.

No. 2684.—The Schoop Metal Spraying Process.

A representative of The Metals Coating Company of America appeared before the Committee and showed samples of various substances that had been coated by this process.

R. B. OWENS,
Secretary.

SECTIONS.

Electrical Section.—A joint meeting of the Section and of the Philadelphia Section of the American Institute of Electrical Engineers was held in the Hall of the Institute on Thursday, November 23, 1916, at 8 P.M.

Mr. Paul Spencer and Mr. H. P. Liversidge presided jointly.

Dr. John B. Whitehead, Professor of Electrical Engineering, Johns Hopkins University, Baltimore, Maryland, delivered a lecture entitled "The Electric Strength of Air and Methods of Measuring High Voltage." Electrical Engineers are chiefly interested in the air as an insulator. Present theories of the electric properties of the air have been developed with experiments at low pressure as a basis. Many observations at atmospheric pressure have not been completely identified with existing theories. Townsend's theory of ionization by collision, and its relation to the laws of the electric strength of air at atmospheric pressure, as based on recent experiments with alternating and continuous potentials, was briefly reviewed in the lecture. Reference was also made to present methods of measuring high potentials. Recent experiments, showing how the electric properties of the air may be used as a standard method of measurement of high voltage, were described.

After a discussion of the paper by Mr. Charles Penrose, Dr. Carl Hering, and others, a rising vote of thanks was extended to the speaker and the meeting adjourned.

T. R. PARRISH,
Acting-Secretary.

Section of Physics and Chemistry.—A stated meeting of the Section was held in the Hall of the Institute on Thursday, December 7, 1916, at 8 o'clock P.M. with Dr. Gellert Alleman in the chair.

G. A. Burrell, chemist in charge of the Laboratory for Gas Investigations in the Experimental Station of the Bureau of Mines, U. S. Department of the Interior delivered an address on "The Extraction of Gasoline from Natural Gas."

The two processes for the extraction of gasoline from natural gas on a commercial scale were described: (1) The condensation of the gasoline by subjection of "casinghead" gas to high pressures and cooling with water at atmospheric temperature, and (2) the absorption of gasoline from "dry" gas in a prepared petroleum oil, followed by distillation with steam, and recovery of the gasoline in the distillate. The history, the underlying physico-chemical principles, the essential installations of machinery, the mode of marketing, and the characteristics of the product were outlined for each process. Statistics were given concerning the quantity of gasoline extracted from natural gas under commercial conditions. The methods for determining the gasoline content of a natural gas were described. The lecture was illustrated with lantern slides. After a discussion of the paper, a vote of thanks was extended to Mr. Burrell, and the meeting adjourned.

JOSEPH S. HEPBURN,
Secretary.

Mechanical and Engineering Section.—A joint meeting of the Section and the American Society of Mechanical Engineers was held in the Hall of the Institute on Thursday, December 14, 1916, at 8 P.M.

Mr. George R. Henderson, President of the Section, and Professor Fernald presided jointly.

Mr. Henderson introduced C. C. Thomas, M.E., Professor of Mechanical Engineering, Johns Hopkins University, Baltimore, Maryland, who delivered an illustrated lecture entitled: "The Cooling of Water for Power Plant Purposes."

Professor Thomas briefly reviewed the methods of cooling water and made special reference to efficiencies obtained particularly with respect to Spray Ponds. He also described a new form of Spray Head and reported upon tests made under widely varied conditions. Factors affecting the efficiencies in Spray Ponds were discussed. The paper was a report of progress rather than a completed investigation.

After an interesting discussion a vote of thanks was extended to the speaker. Adjourned.

T. R. PARRISH,
Acting-Secretary.

MEMBERSHIP NOTES.

ELECTIONS TO MEMBERSHIP.

(Stated Meeting, Board of Managers, December 13, 1916.)

RESIDENT.

MR. HENRY B. COWAN, District Engineer, The Bell Telephone Company of Pennsylvania, and for mail, 502 North 39th Street, Philadelphia, Pa.

MR. P. T. DASHIELL, Engineer, The United Gas Improvement Company, Broad and Arch Streets, Philadelphia, Pa.

MR. FREDERICK C. FEARING, Consulting Engineer, 1088 Drexel Building, Philadelphia, Pa.

MR. F. T. GUCKER, Civil Engineer, 1025 Witherspoon Building, Philadelphia, Pa.

DR. R. W. RUPRECHT, Chemist, 15 North 5th Street, Philadelphia, Pa.

MR. JOHN C. TRAUTWINE, 3d., Civil Engineer, 257 South 4th Street, Philadelphia, Pa.

NON-RESIDENT.

DR. E. G. LOVE, Chemist, 130 East 15th Street, New York, N. Y.

MR. EARL DILLMON MILLS, Metallurgist and Chemist, The Buda Company, Harvey, Illinois.

CHANGES OF ADDRESS.

MR. ROBERT J. ANDERSON, 10839 Pasadena Ave., Cleveland, Ohio.

MR. LEONARD W. COLEMAN, 716–17 Witherspoon Building, Philadelphia, Pa.

MR. MORRIS EBERT, 1706 Green Street, Philadelphia, Pa.

MR. ERNEST JOHANSEN, 439 South 51st Street, Philadelphia, Pa.

MR. MORTON G. LLOYD, 1040 Ontario Street, Oak Park, Ill.

COL. SAMUEL REBER, War Department, Federal Building, Chicago, Ill.

DR. WALTER F. RITTMAN, Fitzsimmons Building, Pittsburgh, Pa.

MR. MELVIN L. SEVERY, 431 South Berendo Street, Los Angeles, Cal.

MR. H. CLYDE SNOOK, 224 Linden Avenue, Oak Park, Ill.

MR. THOMAS SPENCER, 1628 Alameda Street, Lakewood, Cleveland, Ohio.

MR. HENRY R. TOWNE, 420 Park Avenue, New York, N. Y.

NECROLOGY.

Mr. Joshua L. Baily was born at Philadelphia on June 27, 1826, and died at Ardmore, Pennsylvania, on December 6, 1916.

When sixteen years of age Mr. Baily entered the dry goods business in which he continued throughout his life. At the time of his death he was the senior member of the firm of Joshua L. Baily & Company of Philadelphia and New York.

Mr. Baily was intensely interested in many civic affairs and was an active member of a number of charitable organizations.

He became a member of The Franklin Institute on March 4, 1892.

Mr. Charles Alfred Rutter was born in Philadelphia, October 30, 1857, and died at Holly Oak, Delaware, August 3, 1916. He was educated at Rugby Academy, and at the University of Pennsylvania, receiving the degree of Mechanical Engineer from the latter Institution in 1878.

Soon after his graduation he began his professional career as a solicitor of patents, and continued in this field to the time of his death. During the last four years of his life Mr. Rutter was also President of the Essington Ship Building Company, Limited.

While very mechanical in his tastes, Mr. Rutter was catholic in his reading and studies, and possessed a varied fund of useful information. He formed an excellent ethnological collection, the principal articles of which

illustrated the life of the Lenni Lenape Indians. His main diversion was yachting, and in the handling of the yacht he was a master. He had a thorough knowledge of the Delaware and Chesapeake Bays.

Mr. Rutter was a member of the Second Regiment of the National Guard of Pennsylvania, and served in the Spanish War. He was also a member of the Historical Society of Pennsylvania, The University Club, and other organizations. He became a member of The Franklin Institute on March 6, 1880, and served on its Committee on Science and the Arts from 1887 to 1891, and in 1903.

Mr. William Bell Wait was born at Amsterdam, N. Y., on March 25, 1839, and died in New York City on October 25, 1916.

He was educated in the public schools of Albany, N. Y., the Albany Academy and the Albany Normal College.

In 1859 he became a teacher in the New York Institute for the Education of the Blind. Later he studied law and was admitted to the bar in 1862. In October, 1863, he was made emeritus principal of the Institute for the Education of the Blind, which position he held until the time of his death.

He devised the New York point system for the use of the blind and also developed a system of tangible musical notation.

In 1894 Mr. Wait invented the kleidograph, a machine for embossing in the New York Point system on paper, a typewriter for the blind, and later a machine for embossing metal plates to be used in printing books for the blind. For these inventions he was awarded the John Scott Medal by the city of Philadelphia on the recommendation of the Franklin Institute.

The patents for all his inventions were dedicated by him to the public to be used in the amelioration of the conditions of the blind.

Mr. Wait was the author of the following works: The Normal Course of Piano Technic (1888); Harmonic Notation (1888); Phrases of Punctography (1913); The Uniform Type Question (1915); and The Aspects of the Uniform Type Folly (1916).

He became a member of The Franklin Institute on March 27, 1902.

Lt. Col. Theo. Turrettini, Geneva, Switzerland.

Dr. Martin I. Wilbert, Hygienic Laboratory, 25th and E Streets, Washington, D. C.

Mr. Thomas L. Willson, Ottawa, Ontario, Canada.

LIBRARY NOTES.

PURCHASES.

BACON, R. F., and HAMOR, W. A.—The American Petroleum Industry. 2 vols. 1916.

BRUNNER, Richard.—Manufacture of Lubricants, Shoe Polishes and Leather Dressings. 1916.

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ORGANIC CHEMISTRY FOR THE LABORATORY, by W. A. Noyes, Easton, Pa., The Chemical Publishing Company, 1916, 291 pages, illustrations, 8vo, price $2.00.

This is an excellent laboratory manual of organic chemistry. The material offered is extensive—one hundred and thirty-two preparations, which partly accounts for the unusual size of the book. Among these are several which show that the more recent developments have not escaped notice, *e.g.*, one involving the Barbier-Grignard synthesis (p. 73) and the preparation of cyclo-hexane by the catalytic reduction of Sabatier (p. 50). The preparation of zinc-ethyl (p. 61) might well have been omitted. It is dangerous even in moderately skilled hands, and, as a synthetic reagent, zinc-ethyl is, to all intents and purposes, obsolete.

The references to the original literature are remarkably complete and interesting. In the hands of the rare student who desires to use them and who has the necessary linguistic equipment they will be of great value. The reviewer notes with pleasure an uncommon feature in a laboratory manual—the presence of an excellent index. The book is well printed and substantially bound.

ROBERT H. BRADBURY.

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CURRENT TOPICS.

Life of Ammonia Pump Rods. D. L. FAGNAN. (*Power,* vol. 44, No. 20. November 14, 1916.)—As is generally known, the life of the piston rods of ammonia pumps in refrigerating plants is comparatively short, and the rods must be packed quite frequently to prevent leakage of ammonia. The frequent packing wears the rod considerably, and many engineers keep on hand several sizes of packing rings. Keeping on hand several sizes of packing rings and repacking the rod every two or three weeks is a source of loss of ammonia. Inquiries of 230 operators in one year showed that 25 had to renew the rod every three months and to repack it every three weeks. This experience of the operators was corroborated by reports from various ammonia pump manufacturers.

Experiments with materials for pump rods showed that the best service is given by a high grade tool steel. This rod was packed with fibrous packing symmetrically arranged about a central metallic insertion. The rod has been in service for more than a year, running 18 hours a day in summer and 6 to 8 hours a day in winter, and the wear is only 0.002 inch. From five to six drops of oil per minute is fed over the rod, and it is only upon starting, during the first few strokes, that the odor of ammonia is perceptible.

Frequency Standardization. ANON. (*Power,* vol. 44, No. 20, November 14, 1916.)—The first alternating-current system operated at 133 or 125 cycles, single-phase. This seemed to be the correct practice for the generators and transformers used at that time, as this type of apparatus was less expensive to construct than the lower-frequency equipment. In some cases a frequency of 116 cycles was used. With the development of the polyphase system, it was found desirable to use a lower frequency, consequently the sixty-cycle system was adopted. As the transmission voltage was increased, it was again found desirable to decrease the frequency, and 25 cycles found its place in the category of alternating-current systems. This frequency had several advantages, among them low charging current in high-voltage transmission lines and its adaptability for synchronous converters and series railway motors. In the case of the synchronous converter, however, this advantage has almost disappeared, as in late years the sixty-cycle converter has become a successful apparatus. For various reasons there have been a number of other frequencies adopted, such as 66.6, 62.5, 50, 40, 38 and 30 cycles. These are some that we find in our own country. Turning attention to Europe, we find in addition such frequencies as 100, 83, 42, 33 and even 15 cycles, the last being used for railway work.

When it is taken into consideration that many of these systems operating at one frequency cannot be coupled to other systems operating at a different frequency and that, when it is possible, expensive and inefficient machines are required, the necessity for standardizing the frequencies at once becomes apparent. The question of what should be the standard frequency is one that is not definitely settled. In the western part of the country, preference is given to the sixty-cycle system; in the East, the twenty-five cycle is looked upon as preferable. Outside of the fact that twenty-five cycle systems have been installed to a very large extent, and had various advantages at the time they were adopted, there exists at the present time no reason for their continuance except for single-phase railway work. In almost every other case the sixty-cycle system has distinct advantages over systems operating at any other frequency. Therefore, it seems that, when the industry is relieved of this conglomeration of frequencies by the adoption of some standard, the day will be hastened when electricity will be used universally for the transmission of energy.

Multiple Telegraphy System Based on the Attunement of Frequency. ANON. (*Scientific American*, vol. cxl, No. 20, November 11, 1916.)—In Europe there has been recently developed a system of telegraphy which makes it possible for any station to communicate with any other station on the same line without disturbing in the slightest degree the remaining stations. In the new system the receiving instrument of a given station is affected only by an alternating current of given frequency, while its transmitting apparatus is capable of generating any of the frequencies necessary to be received at any of the stations. It is said that the best practice is to employ frequencies between 600 and 1100 per second. It is necessary to avoid employing frequencies of which one is an exact multiple of the other; and the increments between successive frequencies cannot be less than 40 with certainty of reception. Hence without exceeding the limits, 600 to 1100, it is impossible to include more than 14 stations on a line.

In essential principle the receiving instrument consists of a telephone receiver with a steel membrane supported at three nodal points so that it will vibrate distinctly only in response to a current of frequency corresponding to its diameter. Messages may be received by the use of a relay of mono-frequency in combination with a differential relay.

Forced Life Tests of Incandescent Lamps. L. J. LEWINSON. (*Transactions of the Illuminating Engineering Society*, vol. xi, No. 8, November 20, 1916.)—Forced tests of incandescent lamps have been devised primarily for the purpose of surmounting to some extent the obstacle of delay in securing results, which is inherent in

normal life tests of lamps operated at or near their labeled voltage. Incidentally the cost of testing is reduced, principally because of the decrease in energy consumption.

Methods of making forced tests differ somewhat among various laboratories engaged in this kind of work. In one of these, the lamps are measured to determine the voltage at some stated watts per candle. The voltage obtained is then multiplied by a constant factor to determine the forced test voltage. For example, a forced test voltage in common use has been 130 per cent. of the voltage at which tungsten lamps consume 1.23 watts per candle. The equation most conveniently used is:

$$\frac{L_1}{L_2} = \left(\frac{\omega\rho c_1}{\omega\rho c_2}\right)^b$$

where L_1 and $\omega\rho c_1$ and L_2 and $\omega\rho c_2$ are respectively the normal and the forced values of the life and watts per candle, and b a variable exponent. While little authoritative data are available showing the variation of this exponent, there is evidence that the use of a constant exponent over a limited range will yield results which are not subject to considerable error. A forced test however has little value unless proper means of interpretation are at hand, and correction factors determined under one set of conditions must not be applied under other conditions unless their applicability has been proved.

The Future of Forts. H. BERTHAUT. (*The Engineer*, vol. cxxii, No. 3176, November 10, 1916.)—A considerable amount of discussion has been taking place as to the value of permanent fortifications. Certain writers have dwelt on the fact that, in the present war, many fortresses have offered an inadequate resistance or none at all, in order to prove that permanent fortification is a thing of the past, being no longer suited to play any useful part. The logical outcome of this view would be to insist on the abandonment and demolition of all fortresses. We must realize that the science of fortification has not reached finality any more than other sciences. At any particular time it conforms to certain conditions, and these keep on changing. In recent years so rapid have been the advances in the construction of cannons and in the force of explosives, that the science of fortification has been outdistanced.

If fortresses have not proved to be as strong as is essential, that is not the real reason why some of them have offered so brief a resistance; it is rather because, as compared with the attacking forces, their artillery was insufficient and they had an inadequate supply of shells. Make the defending batteries as strong as those that attack, make the conditions equally favorable, and they will certainly prove superior, since they have the advantage of being able to choose the most favorable positions for the guns, and of being better and more solidly constructed. The objection may be raised that the attacking force is fully aware in advance of the exact place occupied by the

object to be attained, while the defense has to ascertain where the attacking batteries are before being able to counter attack. That is so; but it has always been the case, and it is of less importance now than formerly, since aviation affords a very rapid means of locating an attacking battery; and the possibilities of aviation are far from being exhausted.

No indication can be attempted here how fortresses should be constructed, to sketch their elevations and ground plan. That requires long and elaborate study. It has, however, been shown to be possible, in active warfare, to construct effective shelters for troops and solid batteries, with firm platforms for very heavy guns of great calibre, which fire projectiles of enormous weight and shake the substructure very powerfully. It has been shown by experience that these formidable machines, in spite of their weight and bulk, can be moved about, being transported either on rails or even on ordinary roads by means of traction engines. All that can be done in this way in the course of operations, on ground not specially selected and not prepared, can be still better done on foundations chosen and prepared in peace time, on roads and lines laid for this purpose, by employing all such resources as are not available on the field of battle and without exposure to danger. It is therefore possible to render the defense at least as strong as the attack, if not superior to it, by furnishing it with artillery at least equally formidable and by perfecting the installation and the mobility of this material. Permanent fortification must keep on developing: it must be transformed, not abolished. As long as there is progress in the means of attack, the means of defense will likewise progress; it must come about and it can be achieved.

Drinking Water Systems. (Publicity Department, Armstrong Cork Company, Pittsburgh, Pa.)—Legislative enactments, and a growing appreciation of the physical and economic advantages of furnishing a bountiful supply of pure water to workers in all lines of industry, have made the drinking water problem a live issue in almost every industrial establishment. The old bucket-and-dipper method is not only unsanitary, expensive and wasteful of time, but has proven positively injurious on account of the temptation to drink excess quantities at the infrequent opportunities it affords. Many plans have been tried to supply properly cooled pure water to workmen at reasonable cost: buckets of water carried from one point to another, stationary coolers, pipe lines without artificial cooling; more recently, sanitary drinking fountains with water supply cooled by separate ice boxes maintained in conjunction with each fountain. All these methods, however, fail in one or more respects to meet the requirements. Accordingly, plant owners and superintendents have been compelled to look further for the solution of the problem.

In a number of instances, the problem has been solved with remarkable success by the installation of a small refrigerating plant, water cooling tank, insulated distributing lines—with drinking foun-

tains located at convenient points—at a total outlay of less than the operating cost for two years with the old bucket-and-dipper method. There is no economy in the employment of this method despite its seeming simplicity. A steel mill in the Pittsburgh district had been furnishing drinking water in this manner to approximately 1000 men at an annual cost of $5,000. By installing a refrigerated drinking water system at a total expense of $9,000, a permanent method of distribution was secured at a much lower operating cost. The total operating cost when the mill is working full time is $1.82 per employee per year, as against approximately $5.00 by the old method. Besides the marked saving, a material benefit is derived through increased efficiency and reduction in time lost from productive work.

The Elastic Properties of Phosphor-Bronze Wires. A. J. OEHLER. (*Physical Review*, vol. viii, No. 5, November, 1916.)—Studies on platinum-iridium wires used as suspensions for torsion pendulums have shown some remarkable elastic properties of that alloy. The principal one of these was the variation of the period of vibration with the amplitude. It was these studies that made it seem desirable to investigate other alloys for the same properties, and, because of the extensive use of phosphor-bronze wires as delicate suspensions, experiments to that end were made on that alloy.

The experiments showed that there were three distinct states, from one of which to another the wire would change, observable by a distinct change in the law of variation of period of vibration and amplitude. It was found that each state was quite stable in itself unless the wires were subjected to vigorous treatment, such as long continued vibration and long continued annealing. While these peculiarities may be typical of this alloy alone, it is very probable that all alloys have their distinct peculiarities, just as platinum-iridium wires and phosphor-bronze wires have been found to have. The results of the tests indicate that phosphor-bronze wires are not desirable as delicate suspensions, in many cases when they are used. It thus seems desirable that a careful study be made of their crystal structure with the resulting elastic constants, and from the standpoint of their practical uses.

Electric Melting of Non-Ferrous Metals. A. STANSFIELD. (*Brass World*, vol. xii, No. 11, November, 1916.)—The electric melting of non-ferrous metals has not been practised to any great extent, but offers many advantages and will no doubt attain to some importance in the near future. Both arc and resistance furnaces have been used for this purpose. Non-ferrous metals and alloys, such as copper, brass, tungsten, nickel or German silver, can be melted very conveniently, and with little loss, in crucibles placed in carbon resistor furnaces, such as the Hoskins furnace which employs resistor plates, or the Hilberger furnace in which the crucible

itself is made the resistor. The use of the Hilberger furnace for brass melting is said to be inconvenient and expensive on account of the short life of the crucible. The Hering furnace, also, operates on the resistance principle, but in this case the metal itself is the resistor, and this introduces difficulties with metals like copper which have high electrical conductivity. The induction furnace, also, can only have a limited application to the melting of non-ferrous metals on account of their usually high electrical conductivity.

G. H. Clamer and Carl Hering have described very fully the use of the Hering "pinch effect" furnace for melting brass. The power consumption, when melting light brass or bronze chips, was found to be 250 kilowatt-hours per short ton of brass melted. This furnace was to be introduced at the foundry of the Ajax Metal Company in Philadelphia. H. M. St. John has given information with regard to the electric melting of brass. Two types of electrical resistance were employed—the "crucible lift out" type and the tilting type. With the tilting furnace, 280 kilowatt-hours are needed per ton of yellow brass, and 350 kilowatt-hours per ton of red brass, in continuous melting. If the power is only used for ten hours daily, the power consumption will be 400 to 500 kilowatt-hours respectively. With the crucible lift-out furnace, the power consumption is 43 per cent. more than the foregoing figures.

For the economical melting of copper, brass and other metals and alloys, the arc furnace appears to be the most efficient, but in arc furnaces there may be a serious loss by volatilization of metals like zinc, tin, and even copper, while the temperature is far less easily controlled than in the case of resistance furnaces. Messrs. Lyon and Keeney review the furnaces available for the electrical melting of copper and conclude that the Heroult steel furnace is the most suitable. The writer has had some experience with the Rennerfelt arc furnace, and considers this perhaps the most promising type of arc furnace for melting copper, brass and the non-ferrous metals generally. The Rennerfelt furnace has three graphite electrodes, one vertical and two horizontal, which meet in the middle of the furnace. These are supplied with two-phase current, the vertical electrode being the common return for the other two. This furnace, like Stessano's, has the advantage of an arc that is independent of the material to be melted, but the efficiency is better in this case owing to the downward direction of the flame.

Gasoline From Oil Shales. ANON. (*U. S. Geological Survey Press Bulletin,* No. 300, December, 1916.)—In anticipation of the day when, on account of the advancing cost of gasoline and other products obtained from petroleum, it might be found commercially profitable to utilize some of the enormous supply of petroleum to be derived from the distillation of the vast deposits of so-called hydrocarbon shales of the Green River formation of northwestern Colorado and northeastern Utah, the United States Geological Survey

has for three years been making field investigations of these deposits. The examinations have been accompanied by mapping of the areas of hydrocarbon shales and by such field measurements of the thickness of the shales in workable beds and such rude field distillation tests as will afford primary information concerning the amount and richness of the shale in different parts of the region.

Very rough but cautious calculations of the contents of the shale in parts of the area examined indicate that the distillation of shale from beds over 3 feet thick in Colorado alone will yield more than 20,000,000,000 barrels of crude oil, from which more than 2,000,000,000 barrels of gasoline can be extracted by ordinary methods. A report giving the results of these explorations and tests and an account of experiments as to possible gasoline production, both by the ordinary commercial processes and by the Rittman process, are now in press.

Close-Plating. C. H. POLAND. (*Metal Record and Electroplater,* vol. ii, No. 11, November, 1916.)—Close-plating, an art practised for centuries, is carried on now to a very limited extent, and will soon be classed as one of the "lost arts." Till recent times it was regarded as one of the most important industries but it has gone down before the advance of electroplating. A few score years ago close-plating was the only method by which an article could be given the appearance of the precious metals, as all articles plated with either gold or silver were plated by this process. The massive door knobs, name plates, escutcheons, ornaments and tableware found in colonial houses, that were not of solid gold or silver, were all close-plated.

The process consists essentially in soldering on a carefully finished and tinned piece a thin sheet of soft silver shaped to fit the work. The silver sheet is stretched and worked into the crevices until it fits the part closely and then soldered. All these operations are performed with the simplest tools, but consummate skill and rare judgment are essential in the practice of the process.

Electrolytic Cleaning of Silverware. ANON. (*Metal Record and Electroplater,* vol. xi, No. 11, November, 1916.)—A bulletin recently published by the United States Department of Agriculture deals with the electrolytic method of cleaning tarnished silver, which is recommended as an easy and effective way of performing this task. It consists in boiling the article in a soda and salt solution in contact with a clean piece of aluminum or zinc. Experiments made under the direction of the Bureau showed that when silver spoons were polished with whiting paste, nearly 0.01 grain of silver each was lost, whereas with the electrolytic process, only one-twenty-fifth of this amount was wasted.

The tarnish which occurs in silver is not due to oxidation, but to the action of sulphur. The electrolytic cleaning depends upon the slight solubility of the silver sulphide in the hot solutions employed,

its breaking down chemically, and the redeposition on the ware of the silver content when the proper electrical conditions prevail. The presence of both the silver and aluminum or zinc in the hot solution provides the necessary electrical conditions, practically all the silver in the tarnish being returned to the object cleaned. When the silver polishes are used, on the other hand, all the silver in combination in the tarnish is removed. Aluminum is much more satisfactory than zinc for use in this cleaning process, since it does not become coated with a layer of carbonates which could interfere with the chemical reaction. Zinc does form carbonates and if used, must be cleaned frequently in dilute hydrochloric acid. The method is most effective if the solution boils during the cleaning process, and efficiency is rapidly lowered as the temperature of the solution falls below the boiling point.

The Frequent Bursting of Hot Water Pipes in Household Plumbing Systems. F. C. BROWN. (*The Physical Review*, vol. vii, No. 5, November, 1916.)—It seems to have been a common observation by plumbers that the pipes carrying the hot water in a domestic water supply system burst from freezing more frequently than do the pipes carrying the cold water. It is said that the ratio of frequency is at least four to one. The cold water usually freezes so as to lessen the flow of water in the pipes or to stop it entirely, but this freezing is seldom accompanied by bursting. To verify the observations of the plumbers and then to ascertain the physical explanation, experiments were conducted upon a system of glass test-tubes, closed at one end and arranged to approach the conditions found in the ordinary domestic water supply system.

Ordinary tap water freshly drawn was placed in the tube to simulate the conditions in the cold-water pipes. The same tap water, shortly after being boiled, was placed in like tubes to simulate conditions in the hot-water pipes. The tubes were placed in the open air when the outdoor temperatures were at varying degrees below zero. On seven occasions about 50 pairs of tubes were tried, and in every test the tubes of boiled water broke first. When the observations were concluded it was noted that 44 tubes containing boiled water had burst and only four of those containing unboiled water had broken, thus verifying the observations of plumbers.

It was found that the boiled water was invariably undercooled several degrees below zero before freezing commenced and that, after crystallization began, the temperature remained at zero until the entire mass was frozen. The ice was quite clear and solid. The unboiled water always began freezing at zero, and the ice was full of air bubbles and appeared quite slushy, particularly near the central axis of the tube. These air bubbles together with the accompanying impurities form nuclei for crystallization and also act as cushions to react against the expansion of the water by freezing. The air also tends to freeze out toward the middle, and this semi-open center acts

as a safety valve to relieve the pressure caused by freezing. The under-cooling of the air-free water tends to make the center of the tube freeze just as solid as the water near the surface of the tube. Although ordinary tap water freezes more readily than the boiled water, it does not freeze solid, while the boiled water with its freedom from air freezes solid and exerts a greater bursting pressure.

Power Generation by Volcanic Heat. PROF. LUIGGI. (*Engineering*, vol. cii, No. 2655, November 17, 1916.)—In Central Tuscany, near Volterra, there are numerous cracks in the ground from which powerful jets of very hot steam spout high in the air with great violence and constancy, bringing up boric acid, which is very valuable, and other mineral substances of less importance. These powerful jets of super-heated steam are called *Soffioni*—the "blowers"—and have been utilized for many years in the production of boric acid and borax, and occasionally for warming the houses in the near-by village of Larderello. The larger proportion of the steam, however, is lost, having no local application, and with it is lost its very valuable heat.

Experiments demonstrated that each bore can provide steam at a temperature of 150° C. and at the rate of 15,000 to 25,000 kilograms per hour. Encouraged by these results, Prince Ginori-Conti, in 1906, applied the steam to an ordinary steam engine of about 40 horse-power. The experience of several years has shown that this arrangement works well, so far as the mechanical power of the steam is concerned, but that the borax salts and the gases mixed with the steam, especially sulfuric acid—have a corrosive action on the iron parts of the engine and are the cause of frequent repairs. In a later project this difficulty was overcome by driving the engine with steam from pure water generated by the ground steam in a heater. Steam was produced at a pressure of two atmospheres, then passed through a superheater, and afterwards used for driving a 300 horsepower condensing steam turbine, connected directly to a three-phase electric generator which has been supplying the works and villages around Larderello.

Stimulated by the scarcity of coal since the breaking out of the European war, and previous success, a much larger installation was projected and there are now in operation three (3000) kilowatt units supplying power to many towns of Tuscany. This very successful application of volcanic heat to power generation can be increased to practically hundreds of thousands of horse-power as the region of the Soffioni extends for many square miles around Larderello.

Photographic Color Prints on Silk Fabrics. ANON. (*Scientific American*, vol. cxv, No. 24, December 9, 1916.)—A method of printing silk fabrics by color photography, due to Messrs. Vallette and Feret of the Manufacture Nationale des Goblins, France, presents results which appear to be interesting in the sense that the

process makes possible the production of silk fabrics for decorative effects, the perfection of which did not seem to have been hitherto attained in printing. The method is, of course, borrowed from color photography, and consists in making three successive impressions—blue, yellow and red—from three selected photographic plates.

The fabric is rendered sensitive by the aid of mixtures of alkaline phenols and diazo sulphites, products which possess the property of giving coloring matter only through the influence of light. The precision needed in superposing the three impressions is secured by carrying out the work on a special frame, the fabric having been previously provided with metallic eyelets to avoid tearing it. The development of the colors is accomplished with better regularity by exposure to electric light. The method is recommended by its originators as more especially applicable in the treating of articles de luxe of the sort that cannot be well printed by machine.

American Starting and Lighting Systems. A. L. CLAYDEN. *Proceedings of the Institution of Automobile Engineers.* November, 1916.)—The application of electric starting and lighting systems to American automobiles began in 1912 when the Cadillac Company adopted an outfit produced by the Dayton Engineering Laboratories Company of Dayton, Ohio. It is not suggested that the idea originated with this company, but they were the first to produce a machine to be adopted by any motor car manufacturer as standard practice. The Delco apparatus, as it is called, operated on a peculiar patented system which is still used by the Cadillac Company. Briefly it consists of an arrangement of clutches which allows a single armature to operate at comparatively low speed when being used for generating electricity and at comparatively high speed when being used for starting the internal combustion engine.

The introduction of the self-starting Cadillac created so strong a demand for automatic starting that it became obvious within a few months that every competitor would be obliged to employ similar equipment. The tendency at first was to favor the single unit machine capable of acting both as generator and motor because of simplicity, but this was restricted by the Delco patents to an invariable gear ratio between the armature and crankshaft. Such single units are still used in a few cases, and are particularly popular for equipment designed for the Ford car, because they can be produced very cheaply. Where cheapness is not the only consideration, the two-unit system has proved preferable. A comparison of the electrical characteristic of the single-unit and two-unit systems has demonstrated that the latter is the more efficient, but the greatest drawback to the single-unit is the weight of the armature and the impossibility of making satisfactory gearing for connecting it to the crankshaft.

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